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Effects of Encoding Variety and Concurrent-Task Practice on the Transfer and Retention of Complex Skill

Peter S. Winne
Old Dominion University

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by

Peter S. Winne
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Ben B. Morgan, Jr., Chair

ABSTRACT

EFFECTS OF ENCODING VARIETY AND CONCURRENT-TASK PRACTICE ON THE TRANSFER AND RETENTION OF COMPLEX SKILL

Peter S. Winne
Old Dominion University, 1984
Director: Ben B. Morgan, Jr.

The present study investigated the effects of dual-task practice and the variety of problems solved during practice on (a) the acquisition of procedural and declarative skills and the development of concurrent-task skills, and (b) the utilization and maintenance of two types of strategies. Strategies were defined as the use of different mixes of skills pertaining to procedures and specific declarative solutions. Two tasks--mental arithmetic and trigrams--were used to examine problem-solving skills and strategies both immediately following practice and again under delayed conditions. Eighty subjects were randomly assigned to one of four practice conditions by factorially combining practice mode (single- or dual-task) with variety (low and high).

Solution times and errors in solving two kinds of problems--those repeated during practice (old) and novel problems (new)-- were tested under single-, dual-, and triple-task conditions directly after

practice. The results of the analysis indicated that the variety of problems solved during practice influenced the kinds of skills and strategies employed in solving the problems in both tasks. The pattern of results supported the hypothesis that after low-variety practice subjects used a combination of declarative and procedural skills while after high-variety practice all problems were solved procedurally. In addition, dual-task skills facilitated transfer to concurrent-task test conditions, as expected. Concurrent-task skills also were found to moderate the effects of variety in strategy utilization.

The retention of skills was investigated by retesting the subjects 1, 2, 3, or 5 days after the immediate transfer session. Results suggested that the effects of the retention interval were limited to the trigram task. The analyses across levels of retention further suggested that performance strategies continued to be utilized as a function of the variety of practice. In addition the trigram results suggested that optimal retention of skills occurred when either declarative or dual-task skills, but not both, were practiced initially.

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INTRODUCTION

An important characteristic of many jobs and leisure activities is the requirement to manage or time-share concurrent attentional and performance demands of several independent tasks (Jennings & Chiles, 1977). A prime example is flying an airplane, which involves instrument monitoring, scanning, communication, and controlling the aircraft (Gunning, 1980). The performance of these functions often occurs under simultaneous conditions, calling for divided attention, rapid switching between tasks, and concurrent information processing from several sources (Imhoff & Levine, 1981; Passey & McLaurin, 1966). In addition to flying, time-sharing is involved in many other activities. Reading, driving an automobile, and monitoring an array of dials are all examples of complex skills which require the coordination of interdependent elements of performance.

Complex tasks have several defining characteristics which distinguish them from most psychomotor or verbal tasks that have been the subject of learning studies. First, complex tasks are considered to be composed of several independent elements or components performed concurrently (Jennings & Chiles, 1977). The concurrent requirement necessarily involves a large cognitive component, which has been studied under the rubric of cognitive capacity, time-sharing and attention (e.g, Kahneman, 1973; Lane, 1982; Navon & Gopher, 1979; Wickens, 1980). These authors suggest that when two or more tasks must be time-shared, the processing capacity must be allocated among the several tasks, thereby reducing the attention available for a single process. Effective performance of complex tasks involves adjusting to the changing demands within and between tasks by allocating attentional resources (Navon & Gopher, 1979; Wickens, Mountford, & Schreiner, 1981) and by developing specific strategies or modes for responding (Damos & Wickens, 1980; Navon & Gopher, 1979). Complex tasks are also characterized by the variety of different events and sequences that may occur (Battig, 1975, 1979). For example, when driving a car every situation and response is unique. Thus, the skilled performer is able to coordinate performance in response to a series of unpredictable events by applying appropriate alternative control processes (that is, strategies) to the changing environment (Navon & Gopher, 1979; Singer & Gerson, 1979).

Because of its pervasiveness in human activity, the acquisition and transfer of complex skill has considerable theoretical and applied interest to the student of human performance. Beginning with the classic studies of Bryan and Harter (1897, 1899) on the acquisition of telegraphic skill, a relatively large body of human performance research has sought to determine the factors that underlie complex performance (e.g., Adams, 1964; Fitts, 1964; Fitts & Posner, 1967; Fleishman, 1972; Irion, 1966; Navon & Gopher, 1979).

In recent years, skilled performance has been conceptualized as an active process which involves the adoption of task-relevant strategies for handling incoming task information, organizing mental and physical resources and determining when and how to execute responses (Singer, 1978). Recognition of the active and selective nature of performance is based on the notion that there are ultimately many strategies for performing a task which are under the voluntary control of the performer (Lane, 1982). Singer and Gerson (1979) have postulated that performance strategies influence the use of particular cognitive control processes, which are in turn associated with specific mechanisms of performance. For example, they describe the strategy-process-mechanism relationship for a baseball player attempting to hit a pitched ball. To be successful, the batter must deliberately concentrate on a small number of visual cues (strategy), which invokes the cognitive process of selective attention that is, in turn, associated with the sensori-perceptual mechanisms of performance.

From a theoretical perspective, the study of complex skill has important implications for theories of how humans process, organize, store and retrieve information, the limitations of cognitive or mental capacity, and the mechanisms and processes involved in skill. Most current theories of human performance (e.g., Kahneman, 1973; Navon & Gopher, 1979; Wickens, 1980) have explicitly attempted to explain cognitive capabilities and constraints by reference to attentional and time-sharing performance. In addition, the ability of humans to acquire and utilize complex skills is of practical importance in the configuration of man-machine systems, the selection of operators of those systems on the basis of individual differences in cognitive abilites, the allocation of functions to men or machines, and the development of principles and procedures for conducting training (Gopher, 1980; Wickens et al., 1981). Little research has investigated the role of strategies in the acquisition of complex skills. Thus, there is a need to determine the antecedents and characteristics of performance strategies and to investigate their utilization in the acquisition and transfer of complex skills.

The present study is concerned with the acquisition and transfer of performance strategies in complex-skill performance. Specifically, this paper explores two related ideas which are hypothesized as important in understanding the nature of complex skill acquisition. First, the development of complex task skill must be considered in terms of the attentional or time-sharing demands required of concurrent performance. During acquisition the learner must discover ways of controlling or managing the multiple demands of the independent task components so that attentional capacity is not overloaded. As Navon and Gopher (1979) discuss at length, practice provides the opportunity to invoke or adopt a variety of strategies that enable an individual to coordinate component-task demands. In the present study, single- versus dual-task conditions will be used to manipulate attentional demand level.

Second, this study investigates the memory structure of skill encoding. Although little research has addressed memory encoding in complex-skill development, the issue of what is learned during acquisition-- the structure or organization of the skill memory-- has important implications for understanding skill development (Jacoby & Craik, 1978; Newell, 1981; Singer, 1979). Rumulhart and Norman (1981; see also Kolers, 1973) have suggested that knowledge or skill can be classified as either declarative or procedural. Declarative skill refers to the specific content of memory (knowledge that) and procedural skill refers to the processes used to perform a task (knowledge how).

Furthermore, many different strategies can be used to process task information; the type of strategy utilized is presumed to depend, in part, on the mix of skills applied to perform the task. Thus, strategies are devised by individuals as a way of coping with the various demands of a task, of structuring performance. They are attempts to organize activities so as to selectively utilize cognitive processes, for example, by attending to the environment, managing short- and long-term memory storage and retrieval, solving response requirements for components and coordinating intertask requirements (Lane, 1982; Posner, 1973; Singer, 1979; Wickens et al., 1981). Finally, different strategies may be reflected in differential levels of test or transfer performance (Bransford, Franks, Morris, & Stein, 1979).

In this study, declarative and procedural skills are manipulated through the variety of problems presented during practice. More specifically, the development of declarative skill will be emphasized through repeated presentation of a constrained, 5-item set of problems during acquisition. Procedural skill acquisition will be emphasized through presentation of a large variety of problems during practice.

Figure 1 depicts a model of performance strategies for processing task demands reflecting the use of declarative and procedural skills. The model postulates that practice under a low variety of problems would result in encoding specific items. During transfer, when both new and repeated items are presented, these subjects would first search for the previously encoded declarative skill. If the answer was found, responses could be made directly without solving the problem, resulting in relatively fast reaction times. If the search was unsuccessful and the answer was not found, subjects would revert to a computational routine using procedural skills. The sum of the time needed to search for the specific problem plus solve the problem using procedural skills could be expected to take a relatively long time. The subjects who learned math under a high variety of problems presumably would use computations to solve all

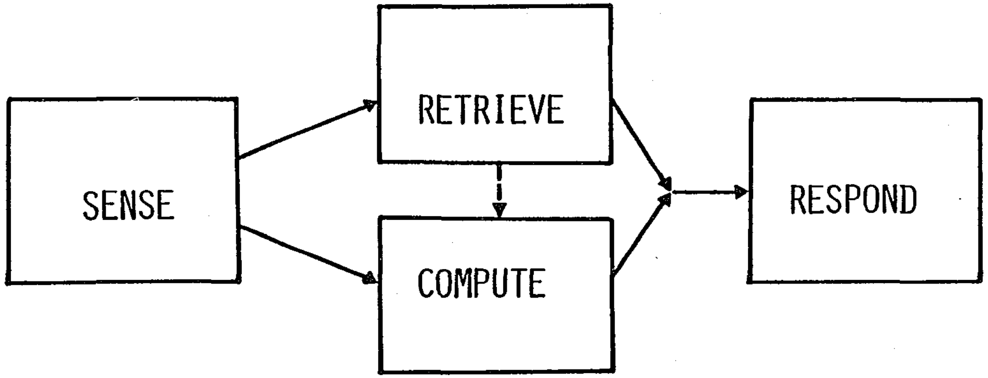

Figure 1. Conceptual Model of Performance Strategies Reflecting Use of Declarative and Procedural Skills

problems, having encoded procedural rather than declarative knowledge. Solution times would be longer than those obtained by direct retrieval but faster than those resulting from unsuccessful search plus subsequent computation by subjects who practice under low-variety conditions.

Finally the type of encoding and the complexity or time-sharing demands of a task might be expected to interact, in terms of both transfer and retention of complex skills. Task load poses a constraint on learning which determines the memory structure of skill, and consequently the development of time-sharing skills. As described below, under single-task conditions, practice should result in the automation of single-task skills but not in the acquisition of those skills needed to manage or coordinate concurrent task performances. However, the availability of different strategies for performing tasks should mediate the effects of complex-task demands.

The Structure of Complex Skill

It has long been recognized that complex skills can be broken down into a number of more elemental skills. Gagne (1970) and others (Fitts, 1964; Miller, Pribram & Galanter, 1960; Robb, 1972) have suggested that the skills for a complex task are organized in a hierarchical structure. Glaser (1982), for example, suggested that there are several distinct types of skill components. Citing research on problem-solving in geometry (from Greeno, 1978), Glaser identified three components that are important in successful performance. These are specific knowledge of the features or patterns of geometric objects, understanding of the rules for proving theorums and making inferences, and strategic knowledge necessary to form plans and organize activity. Glaser argues that the first two skills have typically been included in the design of training programs but that strategic skills have not. "Strategic knowledge is usually relegated to the students general ability to apply what is actually taught (e.g., intelligence). It is possible, however, that such strategic problem solving, if it can be analyzed and understood, could also be explicitly taught" (Glaser, 1982, p. 297).

Strategic skills are also important in tasks requiring concurrent-task performance (Lane, 1982; Navon & Gopher, 1979; Wickens, 1980). While specific component skills are essential for performing the elements in multiple-task performance, as are the skills for dividing attention between task components, strategic skills are important for coordinating performance in a variable-task environment.

Miller et al. (1960) also postulated that skilled behavior sequences are controlled through strategies; employing the language of computers, they suggest that the components of skill are analagous to subroutines in that they consist of relatively fixed, learned parts of the complex skill. These subroutines are called and executed by an executive program or plan in a flexible order during task performance. During the acquisition of a new skill, the existing subroutines are reorganized although there may also be the need to learn new subroutines before a complex skill can be acquired (Fitts & Posner, 1967). Thus, the acquisition of complex skill is considered to depend on both the development of task-specific subroutines or modes of execution and the formulation of an organizing or strategic control plan.

Memory Structure of Skills

Although skill components offer one way of viewing complex skill, it is also useful to consider the way in which memory is encoded for complex skills. It is evident that the organization of memory must play an important role in complex skill acquisition and that the skilled performer has a more elaborate and efficient memory than the novice (Newell, 1981; Schmidt, 1975).

However, it is surprising that memory structures have not been extensively studied in complex skills. Past investigations of skill acquisistion generally took a product-oriented approach to acquisition, emphasizing the role of task conditions such as the distribution of practice, presence or absence of feedback, and part-whole practice on the development of skill (Irion, 1966). Only more recently, has the focus shifted toward understanding the acquisition process in terms of what is learned and how knowledge is organized and recalled from memory (Newell, 1981). As Tulving (1978) suggests, it is important to investigate not only the question of how well a learner has acquired information which was not possessed before, but also what information the learner has acquired in the situation .

In describing a memorial organization for skill, two different models can be postulated. These models differ primarily with respect to the importance of specific or distinctive (i.e., declarative) units of information or the processes or procedures represented (Kolers, 1973, 1975; Rumulhart & Norman, 1981). Rumulhart and Norman (1981) distinguished between these two domains as "knowledge that" (factual knowledge) and "knowledge how" (procedural knowledge). The distinction is similar to the one between episodic and semantic memory (e.g., Lachman, Lachman, & Butterfield, 1979). Kolers (1975) summarizes the two types of encoding clearly:

> Semantically based theories of perception and memory, usually proposing heirarchical organizations of information, [suggest that] the mind is full of knowledge of objects and things, full of concepts, ideas, and images; and it works by sorting, comparing, and coding them. An alternative view holds that mind is procedure, operation and activity; and that what it knows is what it knows how to do. (p. 689)

The difference between the two encoding models is also illustrated by drawing a comparison between verbal learning and motor skill development. One difference in these paradigms has been the importance placed on the specificity of learning. The verbal learning literature emphasizes memory for a list of words or nonsense syllables; the major interest has been the extent to which specific items are recalled (Lachman et al., 1979). Research has focused on the effects of qualitative types of memory encoding on the strength of the memory trace. Under the "levels of processing" rubric (Craik & Lockhart, 1972), a number of studies have indicated that subjects are able to utilize different memnonic strategies (rhyming, category naming to remember target words during verbal list learning; the particular way or strategy in which words are encoded depends on the criteria defined by the task or experimenter (i.e., semantic, rhymes, number of letters, etc.). Varied practice may provide a means of overcoming encoding specificity (Tulving, 1978), leading to a stronger memory trace. Thus, the knowledge may be described as declarative.

In the motor skills domain, acquisition is conceptualized as involving the organization of a class of responses to produce new actions; interest is typically in the transfer of the learned skill to a somewhat different task, not the reproduction of the specific responses learned during training. Schmidt (1975), for example, postulates that during acquisition, the learner organizes knowledge of a skill as an abstract response mode for a class or actions, called a schemata. The specific learned patterns of movement are never exactly reproduced; rather, the schemata serves as a prototype for performing an infinite variety of novel movements. The scemata is assumed to become stronger the more varied the range of practice conditions (Newell, 1981).

It is postulated that complex performance incorporates both the general procedures for responding and the specific elements of skill encoded in memory. The advantage of a skilled performer is attributable both to knowledge of a greater number of specific situations as well as the automation of procedural skills. For example, performance involves carrying out a set of cognitive operations (problem-solving and transformational activities as well as encoding and retrieval processes), which are similar to the skills learned during motor practice; the goal is to form a prototype of the procedures needed to perform under a set of variable or changing demands. In addition, complex skill also involves learning specific instances of knowledge (that is, reoccurring task demands). For example, Chase and Simon (1973) in a study of chess skill, found that the major difference between masters and novices in recalling board positions could be attributed to the masters′ greater memory for known board positions. When pieces were placed randomly on the board, no difference was found between experts and novices in their ability to reproduce positions. Thus, masters were able to excel from their greater degree of declarative knowledge for specific board positions.

The degree to which skills are encoded according to one or the other model is hypothesized to depend of the strategy invoked by the learner. Reder (1982), proposed a model of sentence verification in which both types of encoding are important. Direct retrieval of memorial information may provide a direct fact which verifies a statement as "true." In addition, a person may infer the plausability of a statement through (a) searching for relevant information and (b) using that information to compute the truth of a statement. Reder suggested that of the two strategies, inference of plausibility is the more efficient in the long run. Although the fastest responses would occur after successful attempts at direct retrieval of facts, the time spent in unsuccessful searches, plus the subsequent inferences required, would result in larger average solution times. Based on Reder's analysis, one would expect individuals who practice under a low variety of problems to perform more slowly, on the average, than those who practice under a high variety of problems. However, Reder's task is one which is performed relatively quickly, even when inferential processes are used. When the time needed to solve problems computationally requires a long time relative to the time for retrieving solutions, it might be expected that using retrieval processes would result in an overall advantage, even though excess time is used when searches for specific solutions are unsuccessful.

Strategies and the Acquisition of Skill

A few investigations have shown that strategies which are successful for acquisition *per se* do not necessarily lead to optimal retention or transfer (Bransford et al., 1979; Prather, 1971; Singer & Pease, 1976; Singer & Gaines, 1975). In the instructional development literature, methods of instruction which presumably (but not explicitly) influence memory encoding strategies have been reported to differentially affect different aspects of acquisition. For example, the rate of acquiring a fixed-response sequence on a complex serial manipulation task was enhanced more by guided learning than by use of a self-discovery method; however, retention performance was enhanced by the discovery method (Singer & Pease, 1976). Using the same task, Singer and Gaines (1975) found that the method of instruction most effective for enhancing acquisition (guided learning) did not facilitate transfer to a new but similar task. Prather (1971) reported that early but not late acquisition of a range estimation skill was enhanced by heavily prompted learning; the best transfer, on the other hand, resulted from a trial-and-error learning strategy.

In the motor skills area, the differential effects of memory-enhancement strategies were found for both acquisition and transfer, but not retention of skill during the performance of serial positioning (Singer, Korienek, & Ridsdale, 1980) and a procedural task (Singer, Ridsdale, & Korienek, 1980). In both studies subjects were (a) instructed to use particular memnonic strategies (i.e., elaboration, imagery or chunking), while learning the sequence of positioning movements, or (b) told about the different strategies and instructed to use the strategy of their preference. Differential effects of the strategies were found for both acquisition and transfer, but not for retention. In the procedural task, the self-selected strategy group displayed the fastest acquisition but not the best transfer. In the serial positioning task, imagery and chunking strategies enhanced both acquisition and transfer. In summary, these studies lend some support to the notion that the use of different strategies will affect different aspects of tranfer differently.

The Acquisition of Concurrent-task Skills

Recall that one distinguishing feature of the concurrent-task situation is the requirement to perform several relatively independent task elements in the same general time frame. During concurrent-task skill acquisition there are several potential strategies for handling the demands of multiple components. First, a subject may choose to automate component skills so that the routinized performance of each task element will provide the time needed to accomplish all task requirements (e.g., Navon & Gopher, 1979; Wickens et al., 1981). Each component, however, maintains its integrity.

A second possible way to handle concurrent-task demands is to use attention-management skills to coordinate among tasks. This differs from the first strategy in that efficient allocation of mental resources among tasks, rather than automaticity of the component-task skills, provides the time to respond to all task requirements. Tasks are time-shared in the sense that input, central processing and/or response requirements are interwoven in time. The "executive plan" developed for whole-task performance might include behaviors for scanning different parts of a display (Jennings & Chiles, 1977), processing tasks in parallel (Neisser, 1967; Wickens et al., 1981), or by rapid serial switching between components (Damos & Wickens, 1980).

Finally, a subject might integrate task demands into a single and unified process. Integration refers to the formation of new skills by combining old skills in working memory (Schaeffer, 1975). In the context of concurrent-task performance, the components would become a single cognitive operation. Playing a piano, for example, is best considered not as interweaving of two hands but as the integration of the two hands into a single task (Navon & Gopher, 1979). Similarly, learning to drive an automobile may initially be performed through the coordination of the separate elements (e.g., steering, braking, signalling, etc.), but becomes holistic with practice. Several researchers have suggested that with sufficient practice, the tasks in a dual-task situation may become a single entity (LaBerge, 1973; Navon & Gopher, 1979); the critical factor is whether the components maintain a separate identity. In part, the integration of task components is determined by the degree of component automation, since the ability to perform them in a parallel or time-shared mode depends on not exceeding the limited capacity of a performer.

With respect to concurrent-skill acquisition, the degree to which these three strategies for performing dual-tasks are used is determined by task characteristics, the opportunity to acquire concurrent-task skills, and by the preferences or styles of the learners as well. Most importantly, the learning situation must allow subjects to practice elements concurrently for time-sharing skills to emerge. In a single-task training mode, automaticity of component skills but not time-sharing skills may develop. As Navon and Gopher (1979) suggest, "If poor time-sharing is believed to stem from capacity overload, then each of the activities can be trained separately. . . . However, if the low quality of joint performance is thought to be due to a conflict between the conjoined tasks, the only way for improvement to occur is by training the two tasks simultaneously" (p. 274).

A substantial amount of research supports the need to learn time-sharing skills in addition tothe more specific skills necessary for single-task performance (Adams & Hufford, 1962; Damos & Wickens; Gabriel & Burrows, 1968; North & Gopher, 1976; Gopher & North, 1977; Rieck, Ogden, & Anderson, 1980). Adams and Hufford (1962) found a transient but positive effect of whole- over part-task practice on both retention and relearning of a simulated flight maneuver. Subjects received training on the maneuver and a procedural task under either part-task or concurrent regimens. Both directly after training and after a 10-month interval, concurrent-task practice enhanced performance on the procedural task, but only on the first criterion trial. No differences were observed between the groups on the control maneuver. Adams and Hufford concluded that time-sharing rather than component skills needed to be trained (and retrained).

Further support for a time-sharing skill was obtained in an investigation of attention management under dual-task conditions (North & Gopher, 1976). Conceptualizing time-sharing as the ability to cope with divided-attention demands, they administered a compensatory tracking and a digit processing task both separately and in combination under changing priorities between tasks. Individual performances were highly consistent across different priority conditions during time-shared performance, but generally low or negative correlations were obtained between the component- and dual-task performances. These results supported the authors' conclusion that the ability to manage or selectively allocate attention in response to the changing priority demands differ from those needed to perform the components themselves.

Gopher and North (1977) manipulated task priorities during training on a combination of compensatory tracking and digit processing task. Subjects were trained under single-task conditions, dual-task with equal priorities (e.g., 50% importance for each task) and dual-task with shifting priorities (e.g., 30%, 50%, and 70% importance) across practice trials. Two measures of attention management were computed for the shifting priorities. The first measure, residual variance of the correlation between experimenter-instructed and actual tradeoff between tasks, reflected the degree of linearity in adjusting performance to demand. The second, the slope of actual on desired performance, provided a measure of the subject's response to changes in the priorities. The results indicated that the two tasks were differentially sensitive to dual-task practice. Digit processing skill increased under concurrent-task but not single-task conditions while the more difficult tracking task improved under both single- and dual-task practice. These results suggest that component-task skills can be trained under either single- or dual-task conditions and that in addition to the single-task skills subjects must still learn to manage the concurrent demands.

An investigation of time-sharing acquisition by Damos and Wickens (1980) also supports the importance of concurrent-task training. Subjects were trained to asymptotic performance on a one-dimensional compensatory tracking and a digit processing task, and subsequently received dual-task practice on the combination. The results indicated that dual-task skills increased systematically across dual-task practice trials while the component-task skills remained stable. These results again suggest that the two types of skills are distinct.

Concurrent-task Strategy Acquisition

Although the studies cited above support the notion that single-task and concurrent-task skills are distinct, they do not directly address the use of strategies in acquiring or performing concurrent-task skills. A small number of studies have investigated the role of strategies during the acquisition of concurrent-task skill. Damos and Wickens (1980) identified three performance strategies in dual-task performances. Sixteen subjects, trained on a dual-task ensemble comprised of a digit classification and a short-term memory task, were found to use systematic response patterns for managing concurrent demands. These were (1) a massed pattern in which multiple responses to the same task were made before changing to the second task, (2) an alternating pattern in which subjects switched between tasks, and (3) a simultaneous mode in which responses to both tasks were made less than 100 msec apart. The subjects adopted one of these response modes during the first two minutes of practice and maintained it throughout the session.

These response modes suggest that subjects were using different strategies to manage the dual-task demands. The subjects using the massed strategy may have concentrated on learning the single-task skills to the relative neglect of concurrent-task skills. Switching between tasks or simultaneous responding implies that there was emphasis on learning how to manage the concurrent demands over the requirements of the components alone. The different strategies resulted in differential levels of performance with the simultaneous mode associated with the best, and the massed reponding associated with the poorest, performance.

Damos and Smist (1981) extended the previous study by identifying the response mode for each subject early in practice and then asking some subjects to change their strategies. Subjects who had naturally adopted an alternating strategy were able to use a simultaneous strategy with little difficulty. However, the subjects who initially exhibited a massed pattern had trouble shifting to either an alternating or simultaneous mode, suggesting to Damos and Smist that they were not able to process concurrent demands as efficiently as the other subjects. Further analysis indicated that the the obtained deficit was located in the skill of rapidly switching between the component tasks.

Task Variety and Memory Encoding

The second facet of complex skill which will be investigated here is the effect of varied practice on skill acquisition and transfer. The basic thesis discussed here is that the context for learning, in terms of its degree of variety, results in the adoption of differential strategies for encoding skill memory.

As described earlier, a distinguishing feature of complex tasks is the variety of specific situations or elements which must be processed. A number of investigators have discussed the effects of variation of practice materials as a way to reduce coding specificity in the original encoding (learning) context. Varied practice presumably produces more elaborative encoding of task materials (Battig, 1979; Bransford et al., 1977; Jacoby & Craik, 1978). These authors suggest that the resulting deeper processing leads to better transfer and retention, especially under changed or novel contexts.

Battig (1979) contended that "effective memory depends heavily on multiple and variable processing and on contextual interference and variety" (p. 36). Contextual interference refers to the disruptive aspects of a task (interitem similarity, to example), and to the factors which are extraneous to the task *per se* (a concurrent task, for example; Einstein, 1976). Contextual variety refers to variation in learning conditions during practice trials.

Bransford and his colleagues (Bransford et al., 1979; Morris, Bransford, & Franks, 1977), under the "transfer-appropriate processing" hypothesis, suggest that in most memory encoding tasks the instructions influence the qualitative type of encoding rather than the strength of the trace *per se*; the types of encoding are reflected in transfer performance in the overlap between practice and test performance. Varied practice conditions would presumably allow memory encodings to develop which would be "appropriate" under a range of transfer conditions.

Jacoby and Craik (1978) suggest that the advantage attributable to variable practice contexts comes at a cost to the encoding of specific items. In terms of the previously discussed distinction between declarative and procedural encoding, it might be hypothesized that when practice occurs under a limited variety of conditions, each instance of practice is distinctively encoded as declarative; when the instances exceed a critical level which make it impossible or difficult to distinguish between specific items, a learner will focus on encoding the operations.

In both the verbal and the motor skills domain there is some evidence that varied context does result in better learning, in terms of transfer and delayed retention of skill. Newell and Shapiro (1976) found that variable practice on rapid timing movements led to better performance on a task which was outside the initial practice conditions. Varied training in a linear positioning task by Williams and Rodney (1976) also resulted in better performance during transfer when feedback was not provided.

In a study of concept-attainment skills, Nitsch (1977, reported by Bransford et al., 1979) investigated the effects of same or varied context on transfer performance. Subjects who were tested with cues in the same context as had been encoded during the acquisition phase showed greater initial learning than those who had studied under the varied-context condition. This is to be expected since the test condition provided highly specific study-test overlap for those subjects. The varied-context study condition on the other hand led to better performance during a transfer test comprised of novel examples of the concepts. In a subsequent study by Nitsch (1977, in Bransford et al., 1979), initial same-context training followed by varied-context training resulted in both optimal initial learning and flexible transfer performance.

Although not directly investigating on complex-task performance, these studies suggest that variable-practice conditions will facilitate acquisition of a flexible memory structure which enhances transfer to new task conditions.

Summary and Hypotheses

Enhancing the effectiveness of transfer and retention of complex performance depends on understanding the components of concurrent-task performance-- what is learned and what are the determinants for learning. As Gopher (1980) has put it, "The development of training procedures to improve time-sharing skills is contingent on our ability to identify the components of the learning process as related to the demand of concurrently performed tasks. . . ." (p. 259).

Although researchers in this area are beginning to understand the components and determinants of skill during complex-skill acquisition, there remain many unexplored questions with strong implications for the acquisition of complex skills and the design of training. Understanding the role of strategies in memory encoding during acquisition would make a substantive impact on this important theoretical and applied area.

The purpose of the present study is to investigate the effects of practice mode and contextual variety on the acquisition and retention of concurrent-task skills. Specifically, the research addresses how skills and strategies are acquired and retained as a function of practice under single or dual-task conditions and the variety of problems solved. Transfer performance was tested for two types of items (those repeated during practice and new ones) at three levels of processing load (single-, dual-, and triple-task) immediately after practice, and 1, 2, 3 or 5 days after practice. It was hypothesized that the type of concurrent-task practice (single or dual) would determine the extent of concurrent-task skill acquisition. In addition variety was expected to influence the type of operational skill used to perform the tasks. A low variety of practice was expected to result in development of declarative skills and the use of retrieval processes during transfer; a high variety of practice should result in greater development of procedural skills.

The following research hypotheses were formulated for the immediate transfer session:

1. Between levels of practice mode, the greatest transfer will occur from practice to similar test conditions. Within groups, significant differences between test modes will reflect the respective practice conditions.

2. Between levels of variety, differences in the use of procedural and declarative skills will be found. After a low variety of practice, the speed of solving old problems will be significantly faster, due to the use of declarative skills; after a high variety of practice, solutions for new problems will be significantly faster than after low variety, because of the greater procedural skill.

3. Variety and practice mode will jointly affect the utilization of strategies, since the best transfer of declarative and procedural skills should occur under similar concurrent-task conditions.

With regards to the retention phase, the following additional hypotheses were made:

4. Retention interval will have a linear effect of the decay of skills across all groups.

5. Groups trained under dual-task conditions will exhibit greater retention of all skills than those trained under single-task conditions, due to the facilitative effects of interference during practice.

6. Declarative skills will exhibit greater decay than procedural skills, due to their specific nature.

In addition, higher order effects involving the test mode and item variables were expected to occur, because of differential transfer of the practice variables acting together, but no specific predictions were made.

METHOD

The present study was designed to investigate the acquisition and retention of memory-encoding strategies during complex performance. During the practice phase, 80 subjects were trained on two tasks (mental arithmetic and trigrams) under one of four conditions, formed by combining practice mode (single or dual) and contextual variety (low or high). They were then tested in a complex transfer session immediately following practice and again after 1, 2, 3 or 5 days. The transfer sessions were used to assess the performance of two types of problems (those repeated during practice and new or unpracticed problems) under single-, dual-, and triple-task test conditions.

Subjects and Experimental Groups

Eighty undergraduate male and female students enrolled in Introductory Psychology classes at Old Dominion University served as subjects for the study. The subjects ranged between 18 and 22 years of age. Course experimental credit was given in return for voluntary participation.

Using a randomized blocks procedure, 20 subjects were assigned initially to each of four groups, formed by combining practice mode (single or dual) with contextual variety (low or high). The four groups were (1) Single-task/ Low variety (S-LV), (2) Single-task/ High variety (S-HV), (3) Dual-task/ Low variety (D-LV), and (4) Dual-task/ High variety (D-HV).

For the retention phase of the study, each of the groups was divided randomly into four subgroups of 5 subjects each. These groups were retested at retention intervals of 1, 2, 3, or 5 days after the initial training.

Apparatus

A Z-89 microprocessor with CRT display was used to present all tasks and to record responses. Task presentation, summary feedback after each trial, and rest breaks were controlled through BASIC software programs (See Appendix A). As shown in Figure 2, the three tasks were displayed on distinct portions of the CRT. The mental arithmetic and trigram tasks were presented side by side in the approximate center of the display. The delayed reaction time task was displayed in the upper third of the screen on the extreme right and left sides.

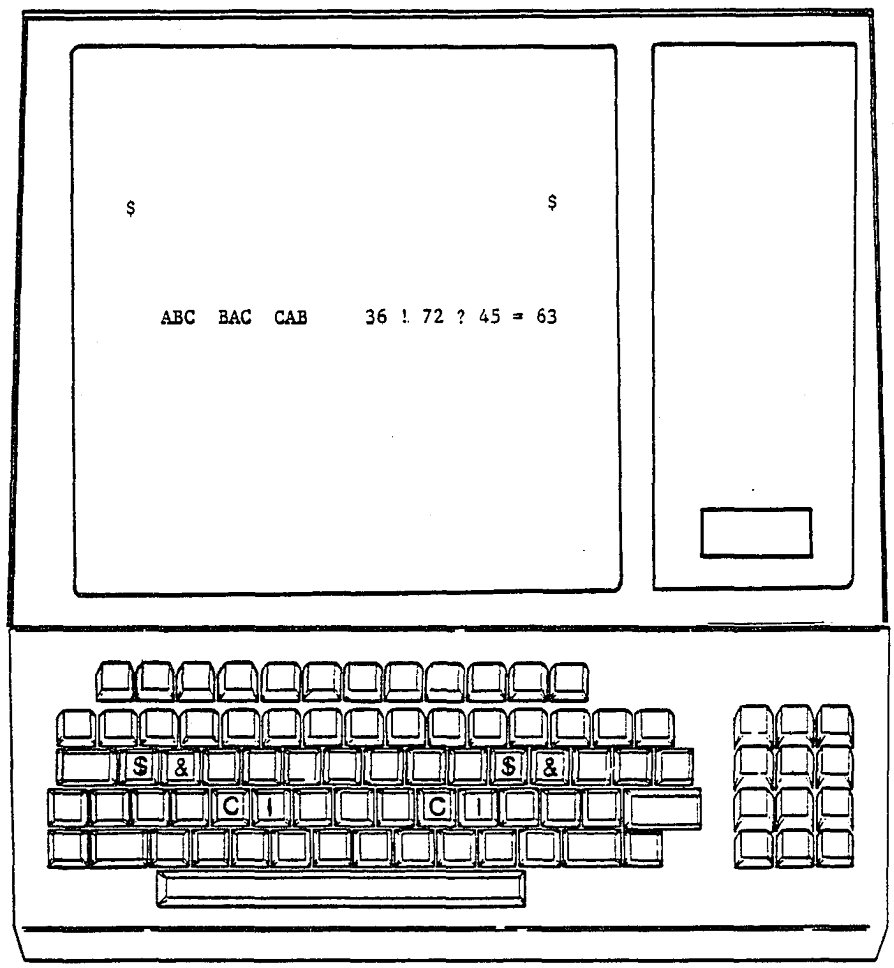

Figure 2. Schematic View of the H-89 CRT and Keyboard, Showing the Three Tasks. See Test for Explanation

A typewriter keyboard attached to the microprocessor was used to make responses. The keys designated for the required responses were clearly marked with symbols identifying them with the task and type of response (Figure 2). All other keys were deactivated (i.e., pressing them did not have any effect).

Tasks

Three tasks-- mental arithmetic (math), trigrams, and a 4-choice delayed reaction time (DRT) task-- were used in the study. They were developed from similar, although substantially more complex and difficult, tasks of the Multiple Task Performance Battery (MTPB), which were designed to tap the behavioral functions required of operators of complex systems (Alluisi,1967). The present tasks were designed in part to provide a set of problem-solving materials representative of complex skills, which could be learned adequately in a one-hour practice session. The tasks were somewhat more complex than those used in most other dual-task studies (e.g., Damos & Wickens, 1980; North & Gopher, 1977; Wickens et al., 1981). In addition, because the focus of the study involved memory encoding, the arithmetic and trigram tasks were administered in a format conducive to recognition and memorization. Description of each of the tasks follows.

Mental arithmetic (math). In this task, modified arithmetic problems of the form X + Y - Z = Answer were presented visually, where X, Y, and Z were different two digit integers between 11 and 99. Subjects were required to determine whether the answer given was correct or incorrect and to respond by pressing one of the two keys marked "C" or "I" designated for the math task. On each presentation the probability of a correct or incorrect answer being displayed was held constant at .50. The problems were modified by using nontraditional symbols for the operands ("!" for "+" and "?" for "-") to interfere with the well-learned arithmetic symbols.

A subset of 5 items was randomly generated off-line for each subject. These "repeated" or "old" problems were used during both the practice and transfer sessions. In the high-variety conditions the 5-item subset was supplemented by additional problems interspersed randomly during practice with a probability of 0.70. During the transfer session, the subset was combined with randomly generated problems for all subjects.

From a functional perspective math taps several components required in many complex jobs. For example, sensory/ perceptual functions, long- and short-term memory, problem-solving skills, and response execution are important components of performance on this task (Alluisi, 1967). As was discussed previously, however, the variety of problems solved during practice is likely to influence the type of skills acquired, and consequently, the performance strategies used to find solutions for problems. As depicted in Figure 1, when specific items are encoded, retrieval processes are expected to be involved in finding solutions; otherwise, procedural skills are expected to be utilized.

Trigrams. The trigram task consisted of three sequences of three letters presented in the form ABC = BCA = CAB (see Figure 2). The subject was required to verify whether the third sequence of letters was correct by deducing the changes from sequence 1 to 2. For example in the problem, ABC = BCA = CAB, the "A" in sequence 1, column 1, is followed in sequence 2, column 1, by a "B"; therefore the "B" in sequence 3 should appear in the same column as the "A" in sequence 2. Following this logic across the columns (i.e., from Row 1 to 2, "B"="C"; "C"="A"), the correct sequence for the third sequence would be "CAB" as shown. The subjects pressed one of the two keys marked "C" or "I" that were designated for the trigram task.

The order of letters in the first two sequences was always random with the constraint that the same letter never appeared in the same columns. The letters A, B, D, E, H, I, J, K, L, Q, R, S, T, X, and Z were used to construct the trigrams. The probability for a correct sequence was .50 for any given problem.

As with math, five "repeated" trigram problems were generated at random for each subject at the beginning of the study and were used throughout training and testing phases. In addition, other trigrams problems were constructed on-line to use during the HV practice session and all transfer sessions.

From a functional standpoint the trigram task is also a problem-solving task, requiring sensory and perceptual functions, procedural activities and execution (Alluisi, 1967). Referring back to Figure 1, the trigrams task presumably would be performed in a manner similar to the already described math task.

Delayed reaction time (DRT). For this task, two target symbols, "$" and "&", were displayed at one of two locations on the extreme sides of the CRT screen (see Figure 2). The subject°s task was to sense the target and retain it in memory while responding to the immediately preceding target. For example, if the first stimulus was a "$" presented on the right and the second stimulus was a "&" presented on the left, the correct response to the second stimulus would be to press the key on the right designated for the "$". Functionally the task was a simple one calling for input, short-term memory, and output. After a response was made a new signal was presented immediately.

On each trial the first stimulus was always a "$" presented at the left side. Thereafter, the symbol and the location were randomly generated with the limitation that the same target/location was not repeated on successive trials. Thus the probability of a particular stimulus on any presentation was .33 and across each trial, was .25.

Procedure

Each subject participated in two sessions, a practice and immediate transfer session requiring approximately two hours and a retention session requiring about one hour. Before the experiment proper, each subject was briefed in general about the experimental task and procedure and was asked to sign a consent form; there were no known dangers to subjects' health nor was deception used. The subjects then read instructions about how to perform the three tasks and the type of feedback they would receive.

After this, the subject was familiarized with the apparatus and tasks with an on-line demonstration. All subjects were provided practice on each of the three tasks before the experiment began.

Practice session. The practice session consisted of six blocks of four 2-minute trials on the math and trigrams tasks, for a total of 24 minutes of practice on each task. The DRT task was not practiced further because there was minimal learning involved for this task (e.g., Damos & Smist, 1980). Standardized instructions were presented on the CRT regarding the type of performance expected (see Appendix B). The instructions differed between single- and dual-task groups but not between low- and high-variety groups.

All tasks were presented in a self-paced fashion. At the beginning of each trial, a problem (either math or trigram) appeared on the screen. After each response was made, feedback was presented by displaying an asterisk (*) next to the item if the response was correct. After one second a new problem was presented until the trial was over. At the end of each trial, the number of responses, percentage of correct responses and mean reaction time per problem was displayed for 15 seconds. After each block of trials an additional 45-second rest break was provided. After the practice session, which required about one hour, a 10-min break was provided.

Single- and dual-task procedures. As discussed before, subjects were trained under one of four combinations of practice mode and variety. The purpose of the practice mode variable was to furnish the groups with different opportunities for learning to coordinate or manage concurrent-task requirements. The single-task (SP) subjects practiced the math and trigram tasks separately in a counterbalanced fashion for a total of 12 trials for each task in order to learn the individual-task skills but not concurrent-task skills.

Under the dual-task (DP) conditions, concurrent-task practice on the math and trigram tasks was administered for all 24 trials, with equal emphasis placed on the performance of each task. Therefore, these subjects had the opportunity to acquire both single- and concurrent-task skills. Assuming that the practice of two tasks under concurrent conditions was equivalent to one-half of the practice under component conditions, the amount of practice was held constant between the groups.

Low- and high-variety procedures. The two levels of contextual variety (low and high) differed with respect to the mix of old and new math and trigram items administered and to their presentation sequence. The purpose of this manipulation was to influence the type of skills (e.g., declarative and procedural) used during acquisition.

Under low-variety (LV) conditions, a set of five items was presented in a repetitive sequence throughout practice. Each trial began with the first problem in the repeated set and proceeded through the five problems before repeating the sequence. In this condition it was assumed that the most efficient learning strategy would be to encode the separate items as declarative knowledge and to use memory retrieval processes during performance of the task.

In the high-variety (HV) conditions, the five repeated items for each task was presented 30% of the time during practice. Novel problems generated in the program were presented 70% of the time. The order of the problems was random within and across trials. Since these conditions were not conducive to memorizing the individual items, it was assumed that procedural or operational skills would be acquired during practice.

<u>Immediate transfer session</u>. After the practice session, each subject was tested in a 14-minute transfer session consisting of seven 2-minute trials. The trials included all possible single-, dual- and triple-task combinations of the three tasks. The order of tasks presented was randomized for each subject, except that the triple-task combination was always last. The procedure for presenting tasks was similar to the DP-LV practice regimen. Repeated and new items were each presented 50% of the time, on the average, in a randomized fashion. Standardized instructions were presented to all subjects on the CRT screen before the test formally began (see Appendix B).

At the beginning of the trial the task or tasks to be performed would appear on the CRT. When a response was made feedback was provided for that task for one second, followed by a new problem. After each trial, summary feedback on the task or tasks was presented for 15 seconds, followed immediately by the next trial. Including instructions, acquisition, and testing, the entire session took about two hours.

Retention transfer session. Subjects returned for another test session 1, 2, 3, or 5 days after the initial session. Each subject was initially presented with a recognition test of repeated and new problems. For each task, 10 problems (five repeated and five new) were presented in the center of the screen. On each presentation, an asterisk appeared in the center for one second, followed by a problem. The problems were presented for one second in a random order. The subjects were instructed to press the key marked "C" designated for the task if they recognized the problem as one repeated during the first session or to press the key marked "I" if it looked unfamiliar.

Retention performance was then tested in a 30-minute session involving two replications of all combinations of single-, dual- and triple-task performance of the three tasks. Standardized instructions reminding each subject how to perform were displayed on the CRT (Appendix B). When ready, the subjects pressed the return key and the session began. The test protocol was identical to the immediate transfer session. After testing, each subject was debriefed on the purpose of the study, and a questionnaire was administered on the types of strategies used. Including the time spent in the testing and the debriefing, the entire session required approximately one hour.

RESULTS

Measures

As discussed earlier, each of the transfer sessions involved performing the three tasks--mental arithmetic, trigrams, and delayed reaction time-- both alone and in all possible combinations, for a total of seven trials. For each subject, the task, test condition, type of item, response latency, trial time and correctness were recorded directly on disk for subsequent analysis. The mean reaction time (RT), percentage of errors, and mean correct response interval (CRI) were calculated directly from each subject's log for each trial and task by means of off-line programs. Inspection of the response logs as well as reports from the subjects indicated that the computer display would sometimes delay for several seconds. When this occurred subjects typically would press the response key repeatedly and rapidly for several times. The delay and subsequent responses were easily identified on the subjects' logs. To correct for these episodes, all math and trigram responses that were less than 0.2 sec or greater than 15.0 sec were culled from the raw data before the measures were calculated.

Mean RT was computed for math and trigrams by summing the response latencies between successive responses and dividing the sums by the number of attempted (total) responses. It should be noted that the calculation of the dual- and triple-task RT in this manner differs from the RT measures reported in some earlier studies (see, for example, Damos & Wickens, 1982). Specifically, during multiple-task conditions, response latencies between successive responses <u>within the same task</u> often serve as the basis for mean RT. The resultant values, however, may be inflated because they include not only the reaction time for the task being measured, but also any intervening latencies for the other task in the pair. In contrast, the present method of computing RT used only the time from the previous response, regardless of the task, to the response being counted.

The percentage of errors and mean CRI were determined in the traditional way. Percentage of errors was simply the ratio of the number of incorrect to the number of attempted responses. Mean CRI was determined by dividing the sum of response time by the number of correct problems.

Immediate Transfer Session

The immediate effects of the factorial combination of the two practice variables, variety (V) and mode (P), were assessed by testing subjects directly after the practice phase was completed. All subjects performed new and repeated items (I) under single-, dual-, and triple-task test mode (T) conditions. Thus, for each subject, each of the measures of performance was computed for each type of item at each of the levels of test mode.

Tests of homogeneity of variance using the Box-Bartlett procedure were conducted on each measure between the four practice groups within each combination of item and test mode. The results of the analyses for the math and trigram tasks are contained in Appendix C. For the math RT and percentage of errors measures, the tests indicated that the distributions were homogeneous ($p > .10$ for all tests). For math CRI, the tests indicated that three of the six distributions (dual-task repeated, and triple-task repeated and new items) violated the assumptions of homogeneity. Similar tests on the trigram data indicated that the RT and CRI data were homogeneous, and that three of the six distributions on the percentage of error measure (dual-task repeated and new items, and triple-task repeated items) were heterogeneous.

The math and trigram CRI measures were each transformed by the formula $X'=\text{Log}2(X+1)$. The test of homogeneity of variance applied to the transformed data indicated that the homogeneity of variance assumptions were not violated ($p > .10$) on any distributions. Consequently, the transformed CRIs were used in all analyses.

To analyze the effects of practice on immediate transfer a 2 X 2 X 2 X 3 analysis of variance (ANOVA)--with practice mode (_P_) and variety (_V_) as between-group factors and item (_I_) and test mode (_T_) as within-subject factors-- was performed on each measure. Scheffe tests were used to make comparisons between specific groups or conditions within groups when the ANOVA indicated that such tests were appropriate. On the RT and error measures, subjects with missing data in any of the within-subject cells were omitted from the analysis. In the math task, 16 out of the 80 original subjects had missing data, leaving a total of 64 subjects. For the trigram analysis, four of the 80 subjects had missing data in at least one of the within-subject conditions, leaving a total of 76 subjects in the analysis. The CRI analysis included only subjects who responded to at least one problem correctly in each within-subject condition. For math, 53 subjects met this criterion and were included in the analysis. For the trigram task, there were a total of 74 subjects with complete data.

Math reaction time and error analysis. Table 1 presents mean RT and percentage of errors for new and repeated math problems as a function of practice conditions. Across groups and conditions, mean RT was 6.12 sec (SD = 2.57), with a range of about 1.5 sec across the practice groups. The percentage of errors averaged 20% (SD = 24) across groups, with a range of 10 percentage points between the four groups.

The analysis of the RT data, summarized in Table 2, indicates that significant main effects were attributable to items and test modes. In addition, there were statistically significant interactions between I and T, and V and I.

Figure 3 depicts the form of the I X T interaction for math RT. Across all other factors, repeated problems were performed significantly faster than new items, $F(1,60) = 50.75$, with a mean difference of about 1.4 seconds. A pattern of increases in solution time as the number of concurrent tasks increased is also evident. Single-task math RT's were significantly

Table 1

Mean Reaction Time (RT; in sec) and Errors for New and Repeated Math Items in the Immediate Transfer Session

Practice Conditions			Type of Item			Difference
Mode	Variety	n	New (N)	Repeated (R)	M	(N - R)
Single	Low	17				
M time			6.12	4.61	5.37	1.51
% error			32	18	25	14
Single	High	18				
M time			7.27	6.37	6.83	0.90
% error			17	18	17	1
Dual	Low	15				
M time			7.60	5.12	6.36	2.48
% error			19	11	15	8
Dual	High	14				
M time			6.26	5.52	5.89	0.74
% error			23	22	22	1
Total		64				
M time			6.82	5.43	6.12	1.74
% error			23	17	20	6

Table 2

Summary of Analysis of Variance for Math RT in the Immediate Transfer Session

Source of Variation	Sum of Squares	df	Mean Square	F
Practice Mode (P)	0.082	1	0.082	< 1.000
Variety (V)	23.477	1	23.477	1.017
P V	88.208	1	88.208	3.821
Subjects within PV	1385.050	60	23.084	---
Test Mode (T)	50.980	2	25.490	7.148*
P T	8.376	2	4.188	1.175
V T	5.268	2	2.634	< 1.000
P V T	0.019	2	0.009	< 1.000
T x Subjects within PV	427.917	120	3.566	---
Item (I)	187.936	1	187.936	50.748*
P I	3.839	1	3.839	1.037
V I	32.478	1	32.478	8.770*
P V I	7.728	1	7.728	2.087
I x Subjects within PV	222.198	60	3.703	---
I T	12.809	2	6.404	3.313*
P I T	10.743	2	5.371	2.779
V I T	2.510	2	1.255	< 1.000
P V I T	4.076	2	2.038	1.054
I T x Subjects within PV	231.949	120	1.933	---
Total	2705.638	383	---	---

* $p < .05$

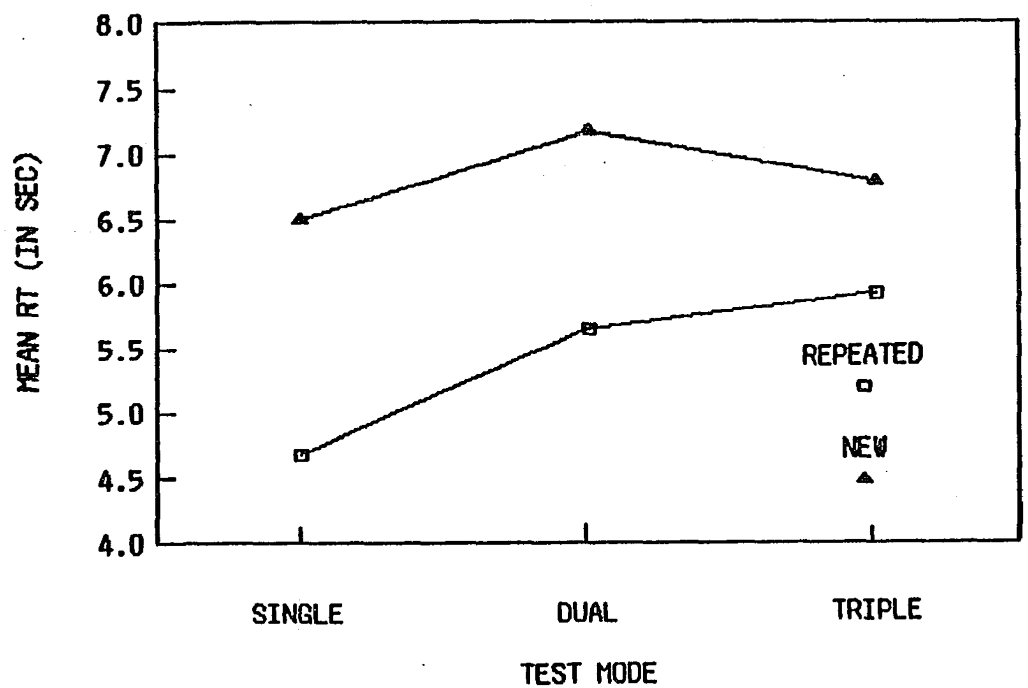

Figure 3. Mean Reaction Time (RT; in sec) for Repeated and New Math Problems in the Immediate Transfer Session as a Function of Test Mode

faster than both dual-task, $F(2,316) = 6.09$, and triple-task, $F(2,316) = 5.26$, RT's, which did not differ significantly from each other. The significant I X T interaction suggests that the effect for mode was moderated by the type of item. Differences between old and new items were significant at all levels of test mode. Only for the repeated items, however, was there a significant difference between the single-task and the two multiple-task modes, $F(5,513) = 5.32$.

Figure 4 shows the V X I interaction for math RT. Post hoc comparisons indicated that the mean differences between old and new items were significant after both LV practice, $F(3,380) = 16.60$, and HV practice, $F(3,380) = 2.99$. In addition, the solution times for repeated items were significantly faster for LV groups than for HV groups, $F(3,380) = 5.72$, while for new items, the between-group differences were not significant, $F(3,380) < 1.00$.

Table 3 summarizes the results of the ANOVA on percentage of errors. Main effects were not obtained for either between-groups variable, but the P X V interaction was significant. Inspection of the mean level of accuracy for the four groups (see Table 1) indicated that errors were about 8% lower for the SP-HV group than the SP-LV group and about 8% higher for the

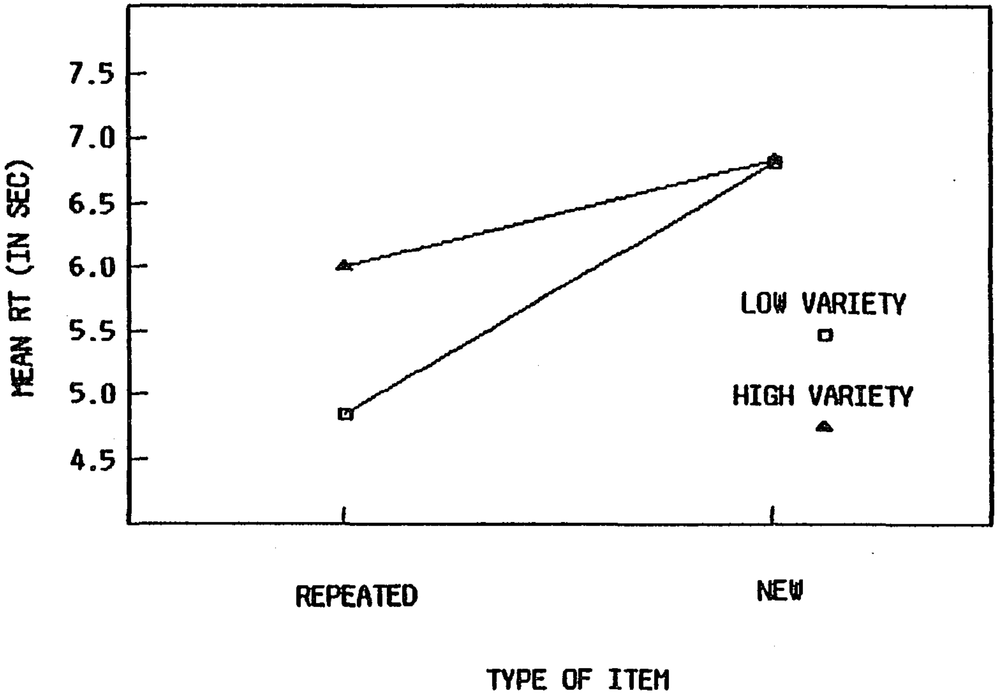

Figure 4. Mean Reaction Time (RT; in sec) for Repeated and New Math Problems in the Immediate Transfer Session After Low- and High-Variety Practice

Table 3

Summary of Analysis of Variance for Math Percentage of Errors in the Immediate Transfer Session

Source of Variation	Sum of Squares	df	Mean Square	F
Practice Mode (P)	584.038	1	584.038	<1.000
Variety (V)	0.335	1	0.335	<1.000
P V	5151.067	1	5151.067	5.384*
Subjects within PV	57407.279	60	956.788	---
Test Mode (T)	400.753	2	200.376	<1.000
P T	1256.488	2	628.244	1.284
V T	254.979	2	127.489	<1.000
P V T	893.447	2	446.724	<1.000
T x Subjects within PV	58731.229	120	489.427	---
Item (I)	2719.490	1	2719.490	4.610*
P I	29.794	1	29.794	<1.000
V I	3098.792	1	3098.792	5.252*
P V I	367.299	1	367.299	<1.000
I x Subjects within PV	35398.417	60	589.974	---
I T	1311.643	2	655.821	1.581
P I T	819.036	2	409.518	<1.000
V I T	500.982	2	250.491	<1.000
P V I T	227.143	2	113.572	<1.000
I T x Subjects within PV	49775.695	120	414.797	---
Total	160196.529	383	---	---

* p <.05

DP-HV than the DP-LV group. Scheffe tests indicated that no pair of means differed significantly.

In addition, there was a significant effect for _I_ and for the _I_ X _V_ interaction. Old (repeated) items were performed more accurately than new items (85% versus 80%). However, as shown by the _V_ X _I_ interaction, in Figure 5, the effect is attributable to differences between items in the LV group only.

With respect to the error measure, the _V_ X _I_ interaction indicates that the variety of items solved during practice had an effect on the relative difficulty of the new and repeated items within groups. The difference in the mean accuracy of old and new items was substantial and significant after LV practice, $F(3,315) = 5.09$, but not after the HV practice, $F(3,315) < 1.00$.

Math correct response interval analysis. Table 4 provides the summary statistics for the raw math CRI measure for each combination of practice mode, variety, and type of item. Across experimental conditions, mean CRI was 8.08 ($SD = 4.67$). Mean CRI, although somewhat higher in terms of absolute value, was similar to the RT measure in its patterns of means and effects.

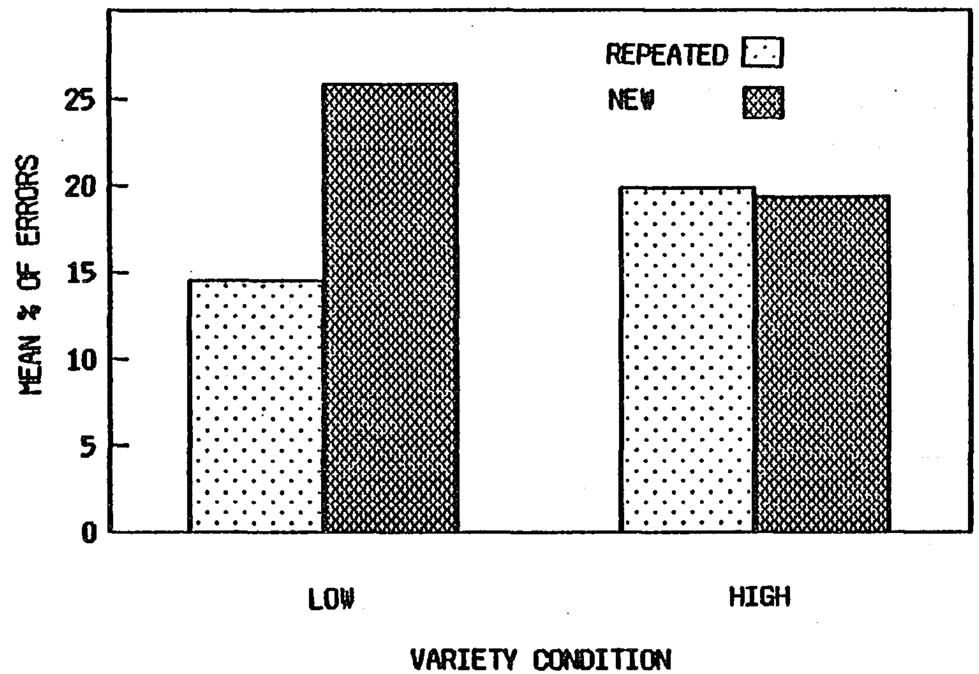

Figure 5. Mean Percentage of Errors for Repeated and New Math Problems in the Immediate Transfer Session After Low- and High-Variety Practice

Table 4

Mean Correct Response Interval (CRI; in sec) for New and Repeated Math Problems in the Immediate Transfer Session

Practice Conditions			Type of Item			Difference
Mode	Variety	n	New (N)	Repeated (R)	M	(N - R)
Single	Low	11				
M time			9.54	6.17	7.86	3.37
Single	High	15				
M time			8.72	8.11	8.41	0.61
Dual	Low	14				
M time			10.08	5.55	7.81	4.53
Dual	High	13				
M time			8.29	8.05	8.18	0.24
Total M time		53	9.45	7.02	8.08	1.06

Table 5 summarizes the effects of the ANOVA conducted on math log CRI. Both I and T emerged as main effects; in addition the simple interactions, V X I and I X T, and the P X I X T triple interaction, were significant. Figure 6 shows the means of log CRI for the I X T interaction. The main effects for the type of item and for test mode are evident. Across modes, repeated items were solved more quickly than new items. Repeated items were also answered faster under the single- than the multiple-task test modes, $F(5,312) = 4.57$. Moreover, the I X T interaction indicated that the differences between old and new items diminished as the number of concurrent tasks increased. Repeated problems were solved more quickly than new items under single-task, $F(5,312) = 39.54$ and dual-task, $F(5,312) = 5.60$, test conditions, but not under the triple-task condition, $F(3,312) < 1.00$.

The V X I interaction is depicted in Figure 7. The difference between repeated and new problems after LV training was significant, $F(3,314) = 16.94$, but not after HV training, $F(3,314) < 1.00$. LV training also resulted in shorter latencies for old problems than did HV training, $F(3,314) = 7.92$.

Table 5

Summary of Analysis of Variance for Math log CRI in the Immediate Transfer Session

Source of Variation	Sum of Squares	df	Mean Square	F
Practice Mode (P)	0.185	1	0.185	<1.000
Variety (V)	2.428	1	2.428	1.904
P V	0.034	1	0.034	<1.000
Subjects within PV	62.491	49	1.275	---
Test Mode (T)	3.503	2	1.751	6.017*
P T	0.089	2	0.044	<1.000
V T	0.595	2	0.297	1.022
P V T	0.633	2	0.317	1.087
T x Subjects within PV	28.528	98	0.291	---
Item (I)	11.771	1	11.771	33.551*
P I	0.058	1	0.058	<1.000
V I	5.910	1	5.910	16.846
P V I	0.279	1	0.279	<1.000
I x Subjects within PV	17.192	49	0.351	---
I T	2.828	2	1.414	8.481*
P I T	1.827	2	0.914	5.480*
V I T	0.070	2	0.035	<1.000
P V I T	0.505	2	0.252	1.514
I T x Subjects within PV	16.340	98	0.167	---
Total	155.266	317	---	---

* p <.05

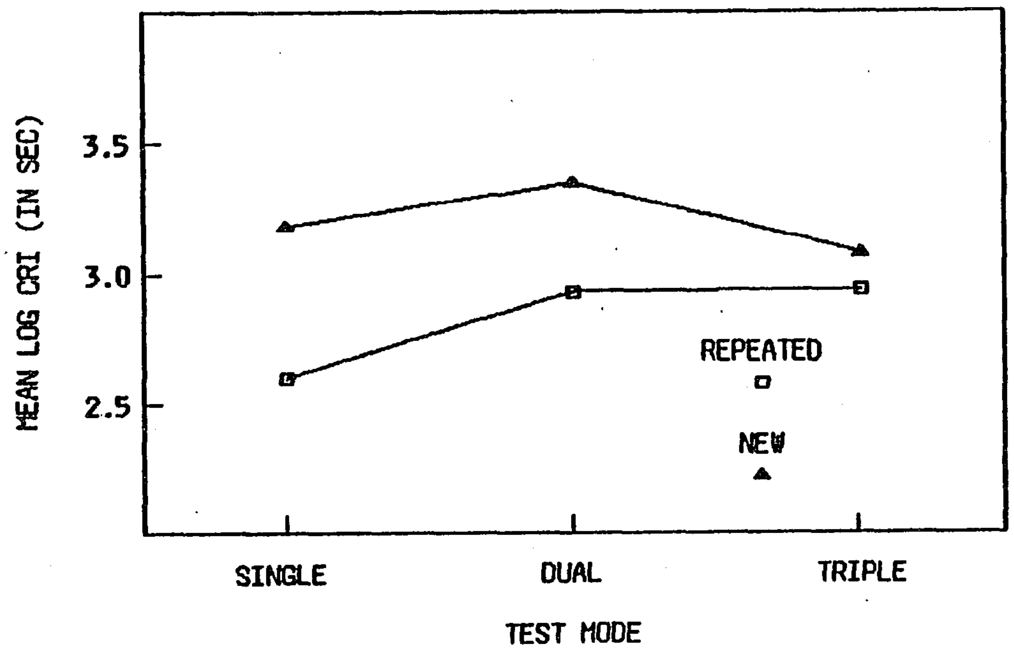

Figure 6. Mean log CRI (in sec) for Repeated and New Math Problems in the Immediate Transfer Session as a Function of Test Mode

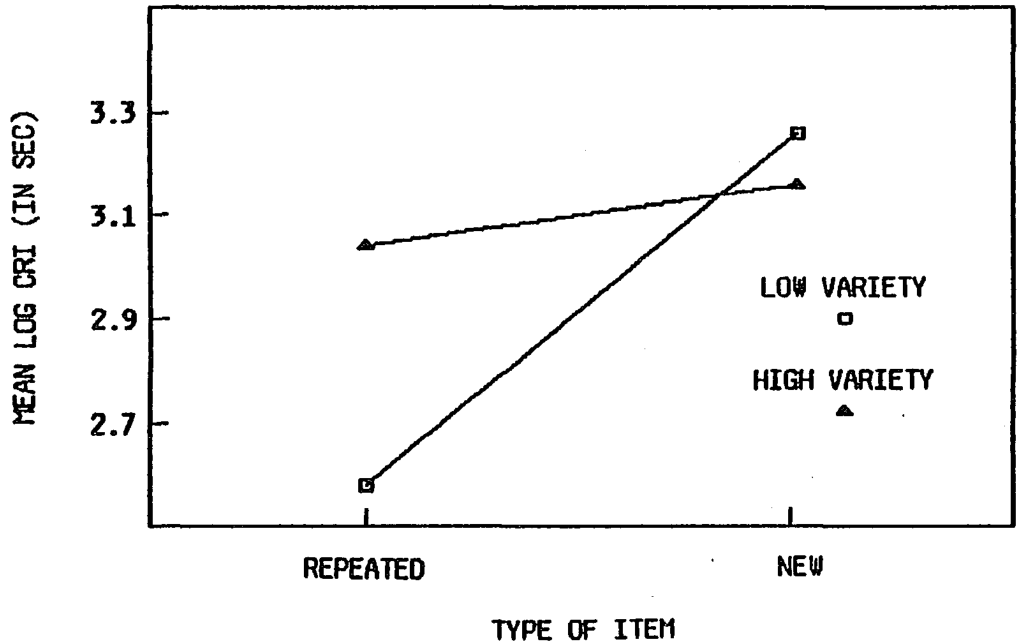

Figure 7. Mean log CRI (in sec) for Repeated and New Math Problems in the Immediate Transfer Session After Low- and High-Variety Practice

Figure 8 depicts the triple interaction between *P*, *I* and *T* for math CRI. In order to explicate the effects of this interaction, separate analyses were conducted within each level of practice mode between item and test mode. The main effects for items were statistically significant after both SP practice, $F(1,25) = 14.38$, $MS = 4.171$, and DP practice, $F(1,26) = 11.84$, $MS = 7.382$; these results indicate that across test modes, new items were solved more slowly than repeated items. There was also a significant test mode effect for the SP group, $F(2,50) = 3.97$, $MS = 1.109$, but not for the DP group, $F(2,52) = 1.97$, $MS = 0.642$. Scheffe tests within SP indicated that the locus of the effect was in the difference between the single-task and dual-task conditions, $F(5,150) = 6.33$.

The patterns of *I* X *T* interactions provide the strongest evidence of the differential performance between the practice groups. After SP practice, the level of test mode strongly affected solution times for old but not new math problems, as indicated by the significant *I* X *T* interaction, $F(2,50) = 11.56$, $MS = 2.207$. These results are shown in the left panel in Figure 8. Specifically, in this group the solution times for new problems were significantly slower than for repeated items during the single-task test condition, $F(5,150) = 5.39$, but not during either

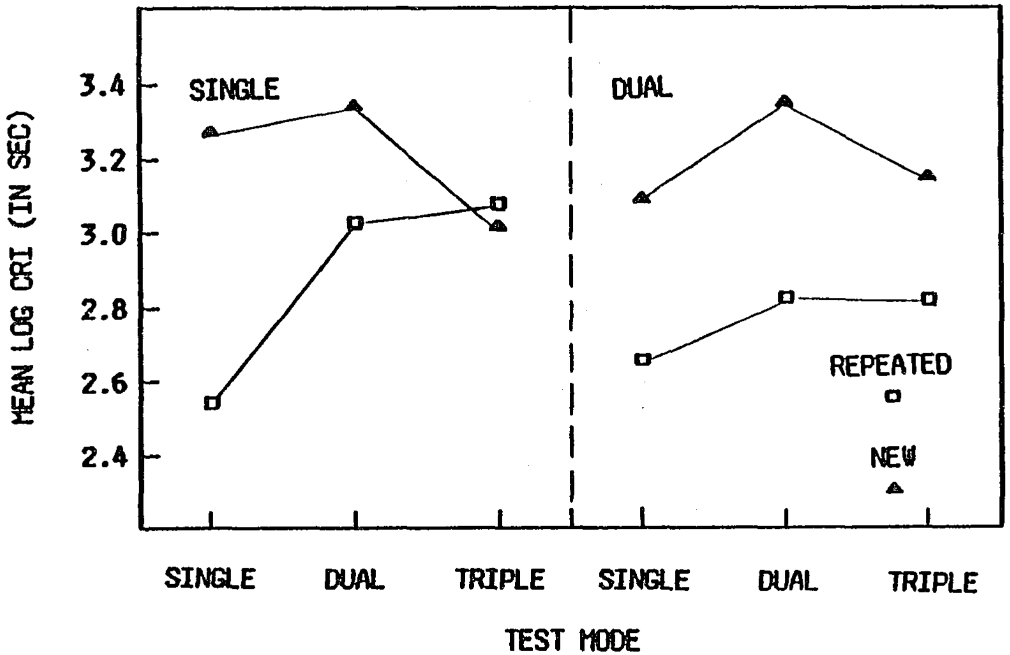

Figure 8. Mean log CRI (in sec) for Repeated and New Math Problems in the Immediate Transfer Session as a Joint Function of Practice Mode and Test Mode

multiple-task condition. In contrast, after DP practice, as shown in the right panel of Figure 8, the differential performance of old and new items was not moderated by test mode $\underline{F}(2,52)<1.00$, $\underline{MS} = 0.124$.

Trigram reaction time and error analysis. Table 6 summarizes mean RT and percentage of errors for the trigram task during immediate transfer. Across all groups, RTs averaged 5.0 seconds ($\underline{SD} = 1.16$). Mean error rate was 7% ($\underline{SD} = 14$) across all conditions and subjects. Across levels of item and test mode, the type of practice apparently made little difference.

The summary of the ANOVA performed on the trigram RT data during the immediate transfer is summarized in Table 7. Significant main effects were found for both items and test modes. In addition, simple interactions were observed between $\underline{P}$ and $\underline{T}$, $\underline{P}$ and $\underline{I}$, and $\underline{V}$ and $\underline{I}$, and the higher-order interactions, $\underline{P}$ X $\underline{V}$ X $\underline{I}$ and $\underline{P}$ X $\underline{V}$ X $\underline{I}$ X $\underline{T}$ were both significant.

Figure 9 depicts mean RT for new and repeated trigrams at each level of test mode. The $\underline{I}$ X $\underline{T}$ interaction was not significant, as shown by the clear independence of the item functions. The difference between old and new items amounted to about .31 sec. In addition, the differences between test conditions is evident across both types of items. During single-task

Table 6

Mean Reaction Time (RT; in sec) and Errors for New and Repeated Trigrams in the Immediate Transfer Session

Practice Conditions			Type of Item			Difference
Mode	Variety	*n*	New (N)	Repeated (R)	*M*	(N - R)
Single	Low	19				
M time			5.06	5.05	5.05	-0.01
% error			11	9	10	-2
Single	High	20				
M time			5.23	5.17	5.20	-0.06
% error			3	10	8	5
Dual	Low	17				
M time			3.83	5.26	4.55	1.43
% error			3	10	6	7
Dual	High	20				
M time			5.01	5.03	5.01	0.02
% error			6	5	5	-1
Total		76				
M time			4.81	5.12	4.97	0.31
% error			6	8	7	2

Table 7

Summary of Analysis of Variance for Trigram RT in the Immediate Transfer Session

Source of Variation	Sum of Squares	df	Mean Square	F
Practice Mode (P)	13.628	1	13.628	< 1.000
Variety (V)	10.947	1	10.947	< 1.000
P V	2.933	1	2.933	< 1.000
Subjects within PV	1404.175	72	19.502	---
Test Mode (T)	198.266	2	99.133	41.003*
P T	18.725	2	9.362	3.872*
V T	1.419	2	0.710	< 1.000
P V T	0.777	2	0.388	< 1.000
T x Subjects within PV	348.149	144	2.418	---
Item (I)	13.631	1	13.631	8.190*
P I	16.496	1	16.496	9.911*
V I	15.133	1	15.133	9.091*
P V I	13.197	1	13.197	7.928*
I x Subjects within PV	119.842	72	1.664	---
I T	0.742	2	0.371	< 1.000
P I T	6.155	2	3.078	2.273
V I T	0.242	2	0.121	< 1.000
P V I T	12.808	2	6.404	4.730*
I T x Subjects within PV	194.955	144	1.354	---
Total	2392.220	449	---	---

* $p < .05$

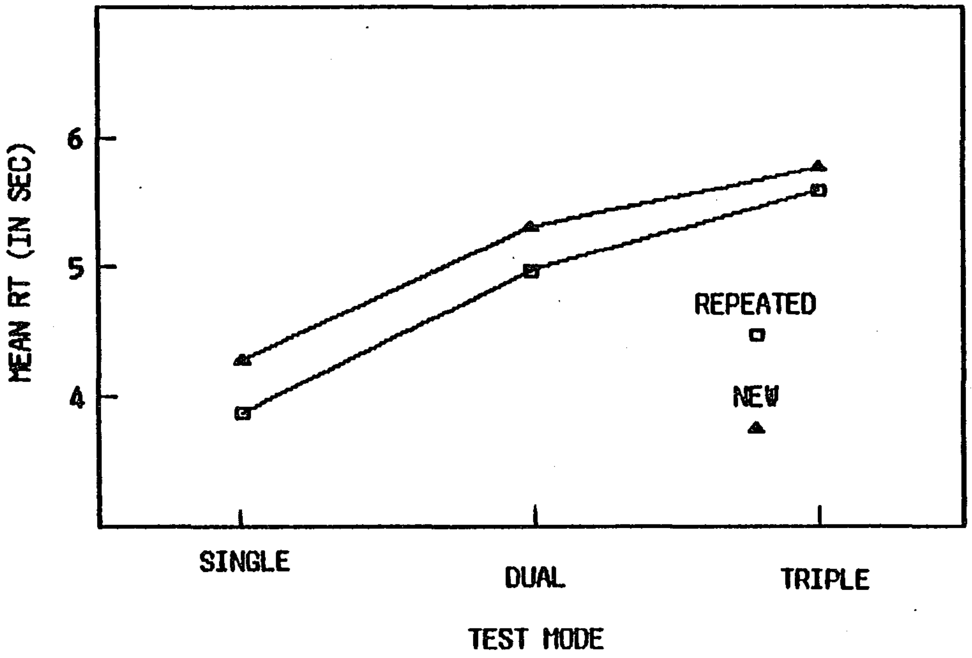

Figure 9. Mean Reaction Time (RT; in sec) for Repeated and New Trigrams in the Immediate Transfer Session as a Function of Test Mode

conditions trigram RTs averaged about 4.1 sec compared to 5.1 and 5.7 sec for the dual- and triple-task conditions,respectively. Scheffe tests indicated that single-task solution times were significantly faster than both dual-task, $F(2,453) = 17.82$, and triple-task solution times, $F(2,453) = 40.52$. Dual- and triple-task RTs were also significantly different, $F(2,453) = 4.60$.

The effects of practice on trigram transfer were observed to interact with items and test modes. Figure 10 shows mean trigram RT as a joint function of P and T. The within-group patterns suggested that test mode had a stronger impact on the SP than DP group. After SP practice single-task performance was significantly faster than dual-task, $F(5,450) = 7.73$, or triple-task performance, $F(5,450) = 10.47$. The multiple-task conditions did not differ. After DP practice, single-task performance differed significantly from triple-task, $F(5,450) = 5.99$, but not dual-task performance. The multiple-task performances within DP were statistically equivalent. Differences between the practice groups during the multiple-task test trials probably reflect differences in dual-task skill which resulted from part- versus -whole task practice.

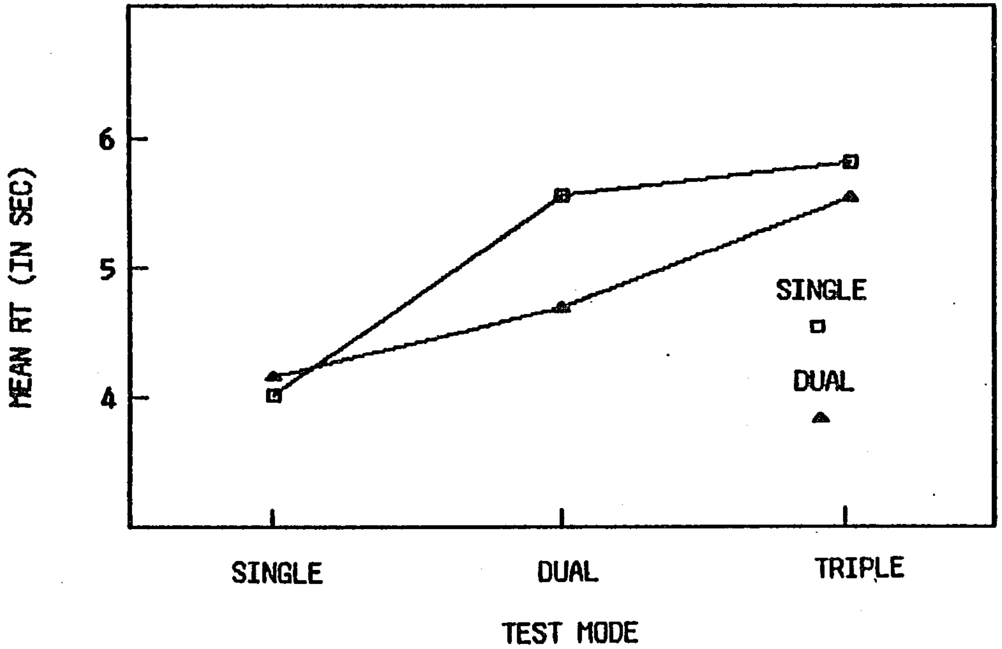

Figure 10. Mean Reaction Time (RT; in sec) for Trigrams in the Immediate Transfer Session as a Joint Function of Practice Mode and Test Mode

The V X I interaction is depicted in Figure 11. After LV practice, solution times for repeated trigrams were significantly faster than for new trigrams, $F(3,452) = 4.88$; after HV practice, the RTs between old and new problems were not significantly different, $F(3,452) < 1.00$. Additionally, repeated problems were solved significantly faster by the LV than by the HV groups, $F(3,452) = 4.69$. With respect to the P X I interaction, RTs for old items were significantly faster than for new items after DP practice, $F(3,452) = 5.00$; after SP practice, the differences between item types were not significant, $F(3,452) < 1.00$.

The breakdowns of the effects for the P X V X I and the P X V X I X T interactions illustrate the complex effects of the practice variables on performance during the immediate transfer session. Considering first the triple interaction (Figure 12), mean trigram solution times across test modes after SP practice appear to be relatively unaffected by differences in either item type or practice. For the groups trained with concurrent practice, on the other hand, a pattern of large differences between new and repeated trigrams emerged after LV but not HV practice. To test the significance of these effects, separate ANOVA's were conducted on the trigram RT measure within each level of practice mode. Within SP, neither the I

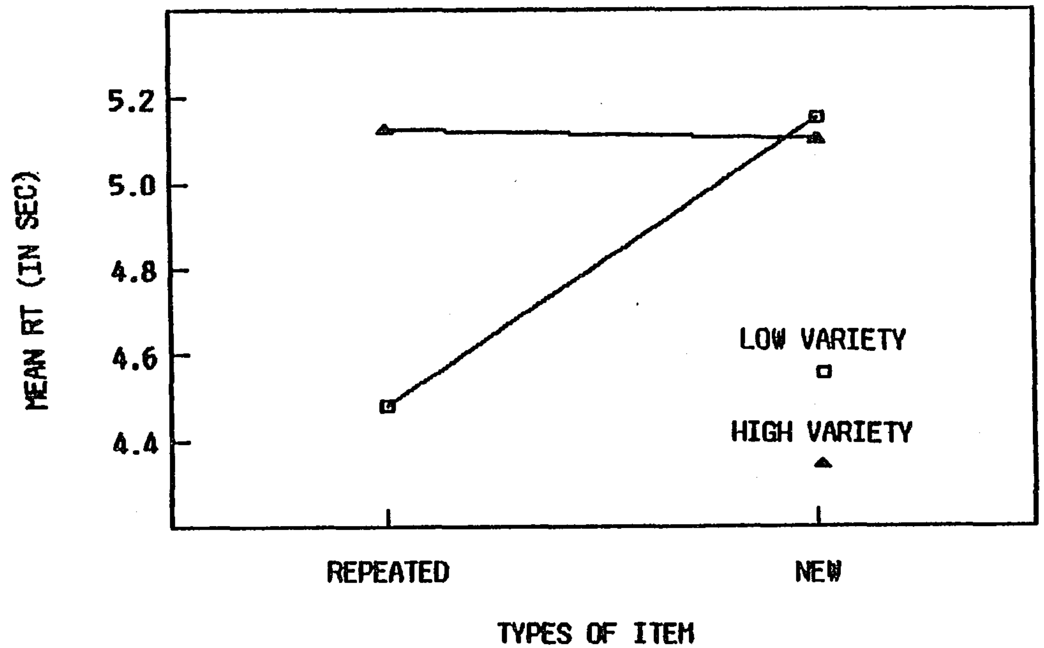

Figure 11. Mean Reaction Time (RT; in sec) for Repeated and New Trigrams in the Immediate Transfer Session After Low- and High-Variety Practice

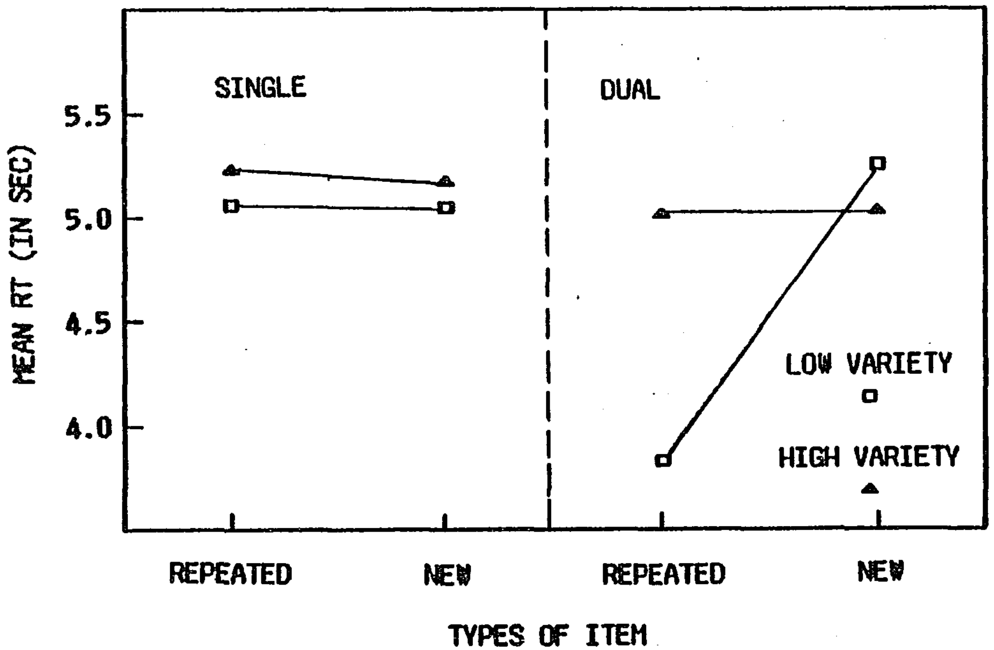

Figure 12. Mean Reaction Time (RT; in sec) for Repeated and New Trigrams in the Immediate Transfer Session as a Joint Function of Practice Mode and Variety

nor the *V* X *I* effects were significant; within DP, significant effects were obtained both for Item, $\underline{F}(1,35) = 13.25$, $\underline{MS} = 29.20$, and for the *V* X *I* interaction, $\underline{F}(1,35) = 12.48$, $\underline{MS} = 27.49$. These findings indicate that variety influenced differences between items only after dual-task practice.

An even clearer picture of the different patterns of performance between the groups emerged from the breakdown of the *P* X *V* X *I* X *T* interaction for trigrams. Within each of the four practice groups, the patterns of the *I* X *T* interaction depicted in Figure 13 reflect the joint contribution of item differences and the concurrent-task requirements to trigram RT performance. Specifically, with respect to test mode differences SP performances exhibit a steeper slope between single-task and the multiple-task conditions than do the DP performances, indicative of the differences in dual-task skill resulting from the DP practice. Moreover, only the DP-LV group exhibited large, systematic differences in solution times for new and repeated trigrams at all levels of test mode. ANOVA's within each practice group were conducted to separate these effects. Table 8 summarizes the *I* X *T* effects. The effect of *T* was significant in all groups. The effect of *I* was significant only in the DP-LV group, with new items performed more slowly at

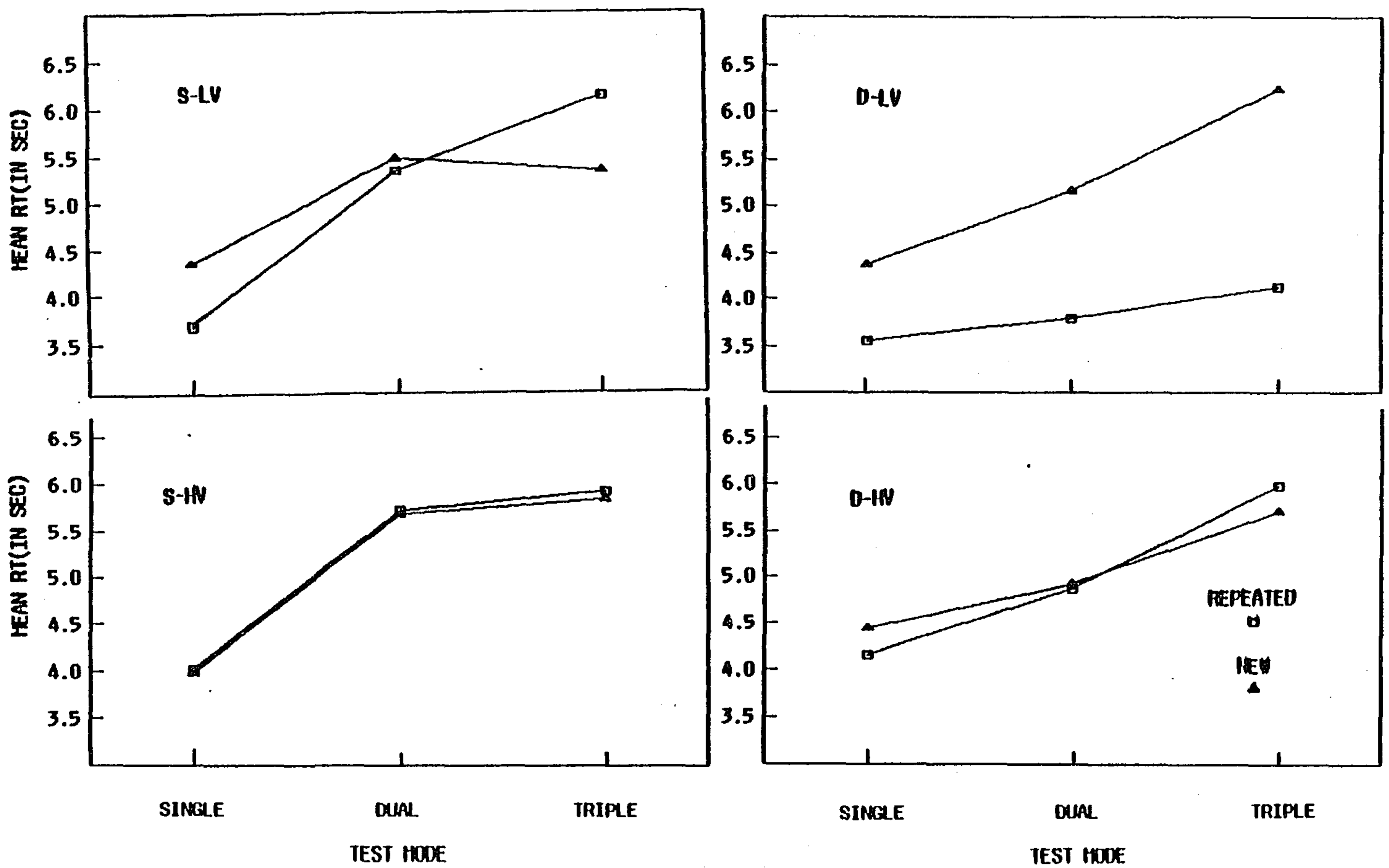

Figure 13. Mean Reaction Time (RT; in sec) for Repeated and New Trigrams in the Immediate Transfer Session at Each Level of Test Mode for Each of the Four Practice Groups

Table 8

Summary of ANOVA 's for Trigram RT Between Items and Test Modes Within Each Practice Condition in the Immediate Transfer Session

Practice Conditions: Mode	Variety	n	Source of Variation	Mean Square	F
Single	Low	19	Item (I)	.003	<1.000
			Test Mode(T)	31.171	10.545*
			I x T	5.203	4.162*
Single	High	20	I	0.103	<1.000
			T	43.519	15.063*
			I x T	0.008	<1.000
Dual	Low	17	I	52.431	13.385*
			T	12.722	5.809*
			I x T	3.639	1.886
Dual	High	20	I	0.014	<1.000
			T	24.573	15.084*
			I x T	.779	<1.000

* $p < .05$

all levels of test mode. Finally, a significant I X T interaction emerged in the SP-LV group. The comparison between means indicated that repeated item were solved significantly faster during single-task than dual-task, $F(5,108) = 4.06$, or triple-task, $F(5,108) = 9.03$, test conditions. No other ltem or I X T effect reached significance.

Considering these joint effects together, the test conditions seemed to have negated the benefit of learning specific items after SP but not after DP practice. In other terms, the DP practice group was apparently able to retrieve solutions for old items while computing answers to new ones. The other three groups, in contrast, apparently solved both new and old problems by computing answers.

The summary of the ANOVA on Errors summarized in Table 9 revealed that there was a significant P X V X I interaction. As shown by the means in Table 6, when the subjects practiced either under a SP-HV or a DP-LV mode, accuracy for new problems was somewhat less than for old problems. When the practice consisted of the SP-HV or the DP-LV combination, old problems were responded to less accurately than new ones. Post hoc comparisons of means indicated that no pair of means differed significantly.

Table 9

Summary of Analysis of Variance on Trigram Percentage of Errors in the Immediate Transfer Session

Source of Variation	Sum of Squares	*df*	Mean Square	*F*
Practice Mode (P)	869.420	1	869.420	2.880
Variety (V)	298.000	1	298.000	<1.000
P V	39.301	1	39.301	<1.000
Subjects within PV	21733.337	72	301.852	---
Test Mode (T)	87.475	2	43.738	<1.000
P T	588.774	2	294.387	1.389
V T	593.518	2	296.759	1.400
P V T	106.373	2	53.186	<1.000
T x Subjects within PV	30516.033	144	211.917	---
Item (I)	505.968	1	505.968	2.902
P I	62.744	1	62.744	<1.000
V I	0.378	1	0.378	<1.000
P V I	1511.346	1	1511.346	8.668*
I x Subjects within PV	12554.381	72	174.366	---
I T	75.202	2	37.601	<1.000
P I T	241.689	2	120.845	<1.000
V I T	123.123	2	61.562	<1.000
P V I T	267.000	2	133.500	<1.000
I T x Subjects within PV	19935.393	144	138.440	---
Total	90109.475	449	---	---

* $p < .05$

Trigram correct response interval analysis. Table 10 displays the means for new and repeated trigram CRI for each of the four groups. Because accuracy was high for most subjects, the pattern of results for the CRI measure was highly similar to the pattern of RT results just discussed. Inspection of the table underscores the lack of substantial overall CRI differences as a function of the practice variables. Across all groups and conditions, the mean CRI was 5.39 seconds (SD = 1.64). Within-subject variables resulted in larger differences. Repeated items were solved about .45 sec faster than new items. Within test modes, CRI averaged 4.35, 5.61 and 6.22 sec, respectively, for the single-, dual-, and triple-task conditions.

Table 11 summarizes the results of the ANOVA conducted on the trigram log CRI data. As in the analysis of RT the main effects of item and mode were significant, as were several interactions of I and T with practice variables, to be discussed below.

In Figure 14, depicting the I X T interaction, the main effects of item and test mode, as well as the lack of a significant interaction, are evident. The increased solution time across groups for new vis-a-vis old trigrams remained nearly constant across test modes. With respect to test modes, single-task

Table 10

Mean Correct Response Interval (CRI; in sec) for New and Repeated Trigrams in the Immediate Transfer Session

Practice Conditions			Type of Item			Difference
Mode	Variety	n	New (N)	Repeated (R)	M	(N - R)
Single	Low	18				
M time			5.53	5.77	5.65	-0.24
Single	High	19				
M time			5.80	5.43	5.62	0.37
Dual	Low	17				
M time			5.87	3.97	4.92	1.90
Dual	High	20				
M time			5.30	5.40	5.35	0.10
Total M time		74	5.62	5.17	5.39	0.45

Table 11

Summary of Analysis of Variance for Trigram log CRI in the Immediate Transfer Session

Source of Variation	Sum of Squares	*df*	Mean Square	*F*
Practice Mode (P)	2.281	1	2.281	1.931
Variety (V)	0.583	1	0.583	< 1.000
P V	0.356	1	0.356	< 1.000
Subjects within PV	82.678	70	1.181	---
Test Mode (T)	11.888	2	5.944	33.242*
P T	1.382	2	0.691	3.865*
V T	0.051	2	0.026	< 1.000
P V T	0.224	2	0.112	< 1.000
T x Subjects within PV	25.033	140	0.179	---
Item (I)	1.853	1	1.853	15.096*
P I	1.061	1	1.061	8.648*
V I	0.773	1	0.773	6.299*
P V I	1.654	1	1.654	13.475*
I x Subjects within PV	8.591	70	0.123	---
I T	0.011	2	0.005	< 1.000
P I T	0.181	2	0.090	< 1.000
V I T	0.033	2	0.017	< 1.000
P V I T	0.934	2	0.467	4.482*
I T x Subjects within PV	14.585	140	0.104	---
Total	154.152	443	---	---

* $p < .05$

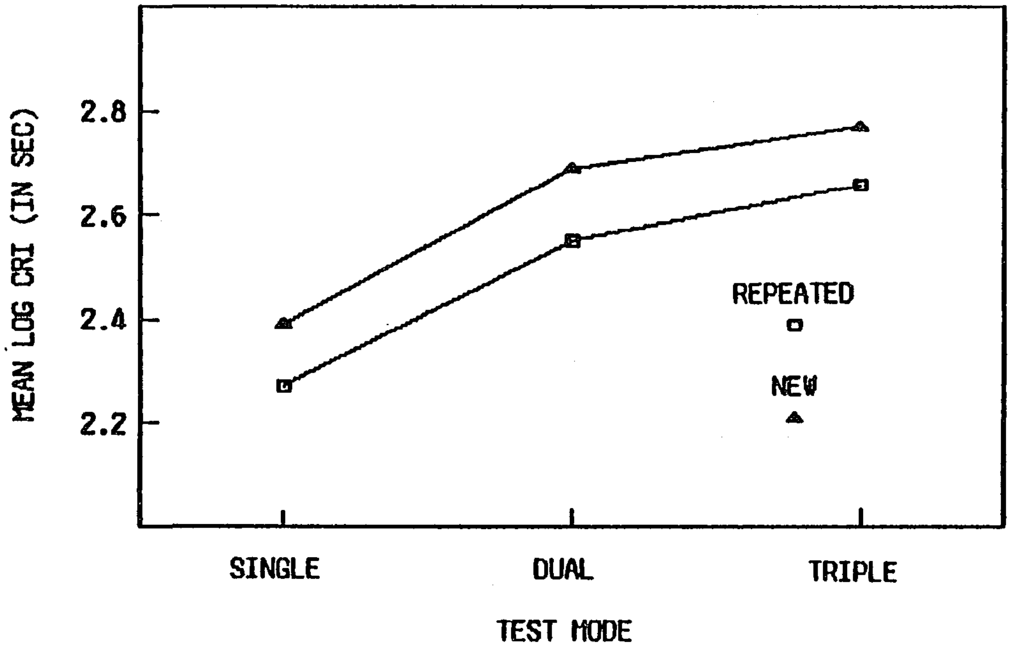

Figure 14. Mean log CRI (in sec) for Repeated and New Trigrams in the Immediate Transfer Session as a Function of Test Mode

performance differed significantly from both dual-task, $F(2,41) = 17.04$, and triple-task, $F(2,441) = 37.02$, performances, which did not differ from each other.

In addition, as was found in the RT measure, the simple interactions, P X T, P X I and V X I, as well as the higher-order interactions, P X V X I and P X V X I X T, reached significance. In all of these interactions, the patterns of mean trigram CRI were highly similar to the patterns discussed previously for the trigram RT measure, and suggest that practice under dual-task conditions with the constrained problem set was necessary to systematically retrieve learned problems during the transfer session. As shown in Figure 15, which depicts the I X T interaction within each of the four practice groups, it is evident that only the DP-LV group clearly differentiated between types of trigrams across levels of test mode. Separate ANOVA's conducted between I and T within each of the four practice groups (see Table 12) substantiates this observation. Furthermore, the effects and patterns obtained for the P X I, V X I, and P X V X I interactions, can be traced generally to the DP-LV performance. Each of these interactions is marked by significant differences between old and new trigrams in the comparisons which includes the DP-LV group. Specifically, for the V X I interaction, there was a

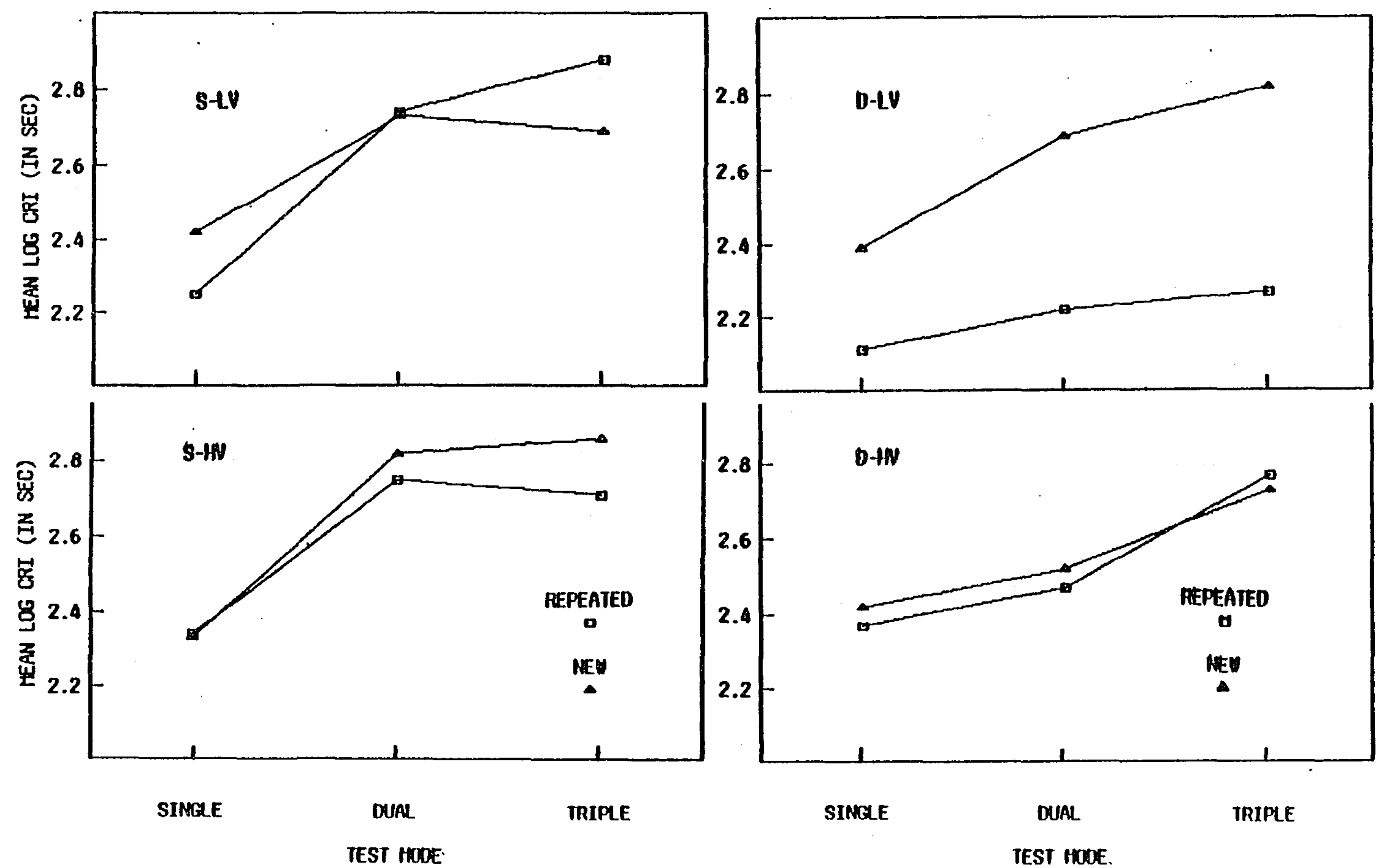

Figure 15. Mean log CRI (in sec) for Repeated and New Trigrams at Each Level of Test Mode in the Immediate Transfer Session for Each of the Four Practice Groups

Table 12

Summary of ANOVA's Between Items and Test Modes for log CRI Within Each Practice Condition in the Immediate Transfer Session

Practice Conditions Mode Variety	*n*	Source of Variation	Mean Square	*F*
Single Low	18	Item (I)	0.001	< 1.00
		Test Mode(T)	2.200	9.98*
		I x T	0.305	2.57
Single High	19	I	0.140	1.07
		T	2.571	13.67*
		I x T	0.067	< 1.00
Dual Low	17	I	4.788	27.16*
		T	0.756	4.24*
		I x T	0.163	1.86
Dual High	20	I	0.014	< 1.00
		T	1.308	9.73*
		I x T	0.028	< 1.00

* $p < .05$

significant difference between new and repeated trigram solution times for the combined LV groups, $F(3,440) = 6.10$, but not for the combined HV group, $F(3,440) < 1.00$. For the P X I effect, the difference between old and new items was significant after DP practice, $F(3,440) = 6.69$, but not after SP practice, $F(3,440) < 1.00$. With respect to the P X V X I interaction, depicted in Figure 16, the ANOVA's performed within each level of P indicated that there were no significant effects on trigram CRI as a function of V, I, or their interaction after SP practice; after DP practice, there was a significant main effect for items, $F(1,35) = 24.74$, $MS = 2.85$, and a significant V X I interaction, $F(1,35) = 20.28$, $MS = 2.34$. Again, the locus of the interaction was the DP-LV group.

Referring back to Figure 15, the pattern of CRI means within group and across levels of practice mode suggests that there were test mode effects and an interaction between P and T. As Table 12 shows, the effect of T was significant within each group. Scheffe tests conducted between modes indicated that after SP practice, single-task trigram performance was significantly faster than dual-task performance both in the LV, $F(2,105) = 6.53$, and HV group, $F(2,111) = 10.76$. After DP practice, the single- and dual-task performances were statistically equivalent at both

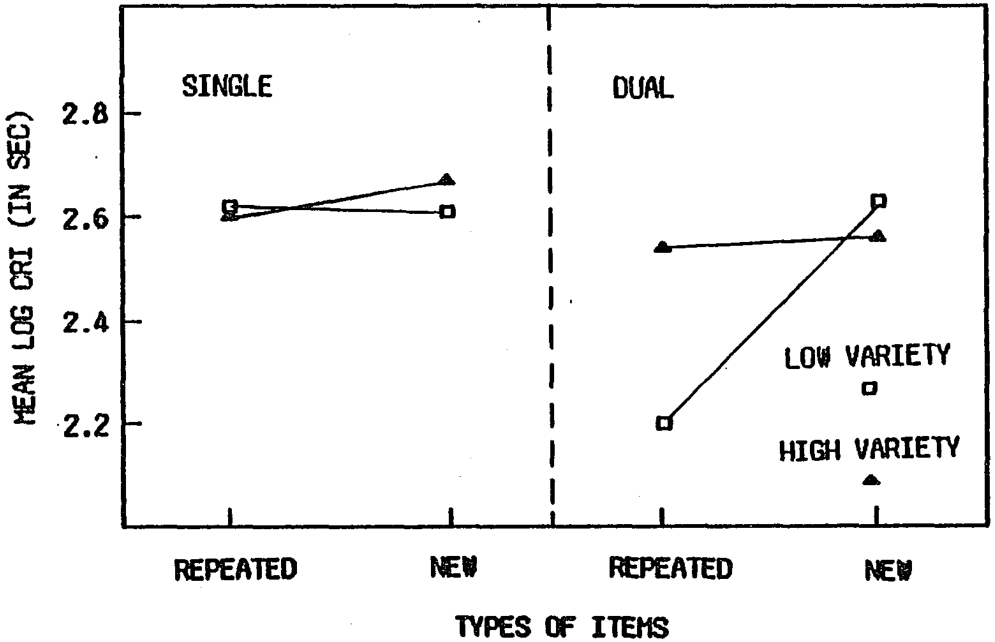

Figure 16. Mean log CRI (in sec) for Repeated and New Trigrams in the Immediate Transfer Session as a Joint Function of Practice Mode and Variety

levels of variety.

Finally, an ANOVA between *P* and *T* was conducted at each level of *V*. Within LV practice groups, the interaction was not significant, $F(2,66)<1.00$; within HV groups, a significant *P* X *T* interaction was obtained, $F(2,74) = 3.96$, consistent with the overall finding of differences in trigram performance between SP and DP groups as a function of test mode.

Retention Performance

As discussed earlier, a major focus of this study was to investigate the extent to which problem-solving skills were retained across intervals of one to five days as a function of the practice conditions. To examine retention performance, five of the 20 subjects who were initially trained under each of the factorial combinations of *P* and *V* were retested either 1, 2, 3 or 5 days after the initial transfer session, forming a total of sixteen groups. The retention transfer session involved 14 trials with two replications of all combinations of single-, dual-, and triple-task combinations of the math, trigram and delayed reaction time tasks for each subject.

Transformations. Tests of homogeneity of variance were conducted on each of the within-subject measures across the 16 groups (see Appendix C). For math, the tests indicated that homogeneity of variance assumptions were not violated for the RT measures. However, the percentage of errors for single-task old and triple-task new items were heterogeneous. For math CRI, new items in single-task conditions, and repeated items performed under the dual- and triple-task conditions were heterogeneous. For the trigram task, homogeneity tests indicated that the distributions for single-task old and dual-task new RT were heterogeneous, as were those for dual-task old and new percentage of errors. For the CRI measure both single- and dual-task new and repeated distributions also violated homogeneity assumptions.

The transformation $X' = \log 2\ (X+1)$ was applied to the CRI data for each subject. Tests of homogeneity of variance on the resultant log CRI distributions indicated that the math measures were homogeneous. Although the trigram CRI data still violated the assumptions of homogeneity, the transformed data was used in subsequent analyses.

In order to analyze the effects of retention transfer, each measure for each task was submitted to a 2 X 2 X 4 X 2 X 3 ANOVA in which there were two levels of practice mode (P) and variety (V), four levels of retention interval (R), two levels of items (I) and three levels of test mode (_T_). _P_, _V_, and _R_ were between-groups effects and _I_ and _T_ were crossed with subjects. Complex interactions were broken down through the use of simpler ANOVA's, and Scheffe tests were used to make specific comparisons when the ANOVA indicated that such tests were appropriate.

For each task, RT, percentage of errors, and log CRI were analyzed separately. When subjects did not perform at least one problem in each combination of _I_ X _T_, they were omitted from the RT and error analyses. In addition, if they failed to perform at least one problem correctly in all of the six within-subject conditions, they were omitted from the analysis of CRI. For math, three subjects were omitted from the RT and errors analyses for a total of 77. For CRI, five subjects were not used, leaving a total of 75. In the trigram analyses one subject was omitted, leaving a total of 79.

Math reaction time and error analysis. Mean RT and percentage of errors for new and repeated math items as a function of practice conditions are presented in Table 13. Across the 77 subjects used in the analysis, the mean solution time for problems was 5.49 sec, (_SD_ = 2.38). Between the one and five day retention intervals, solution time increased about one

Table 13

Mean Reaction time (RT; in sec) and Errors for New and Repeated Math Items in the Retention Transfer Session

Practice Conditions			Type of Item			Difference
Mode	Variety	n	New (N)	Repeated (R)	M	(N - R)
Single	Low	20				
M time			5.80	3.98	4.89	1.82
% error			29	18	24	11
Single	High	19				
M time			6.28	4.92	5.60	1.36
% error			18	14	16	4
Dual	Low	19				
M time			6.98	4.59	5.78	2.39
% error			18	9	13	9
Dual	High	19				
M time			6.26	5.17	5.71	1.09
% error			21	20	21	1
Total		77				
M time			6.32	4.66	5.49	1.66
% error			22	15	18	6

second, from about 5.2 to 6.2 seconds. Repeated problems were performed more quickly than new problems, requiring an average of 4.7 compared to 6.3 sec. The differences between test modes across other factors were less than 0.5 seconds. Across all subjects, mean rate of errors amounted to 18% (*SD* = 19). Old items were performed about 6% more accurately than new ones.

Table 14 summarizes the results of the ANOVA performed on the math RT retention data. A main effect was found for Item and in addition, the *V* X *I* interaction was significant. Figure 17 depicts this interaction. New items were solved significantly more slowly than repeated items, both after LV practice, $F(3,458) = 26.33$, and HV practice, $F(3,458) = 8.80$. For repeated items, the differences between the groups was also significant, $F(3,458) = 3.40$. The pattern suggests that practice with a smaller item set resulted in better retention, but that both groups recognized the occurrence of repeated math problems and solved them more quickly than new problems.

Table 15 summarizes the results of the ANOVA on errors. The main effect of *I* was significant, as were the *V* X *I* and the *P* X *V* interactions. The *P* X *V* interaction, in Table 13, probably occurred because of the pattern of differences between the LV and HV groups

Table 14

Summary of Analysis of Variance for Math RT in the Retention Transfer Session

Source of Variation	Sum of Squares	df	Mean Square	F
Practice Mode (P)	35.987	1	35.987	1.552
Variety (V)	13.049	1	13.049	< 1.000
Retention (R)	84.364	3	28.121	1.213
P V	15.002	1	15.002	< 1.000
P R	47.433	3	15.811	< 1.000
V R	19.391	3	6.464	< 1.000
P V R	42.409	3	14.136	< 1.000
Subjects within PVR	1414.002	61	23.180	---
Test Mode (T)	3.569	2	1.785	1.184
P T	0.580	2	0.290	< 1.000
V T	3.087	2	1.544	1.024
R T	1.261	6	0.210	< 1.000
P V T	3.182	2	1.591	1.056
P R T	10.546	6	1.758	1.167
V R T	5.692	6	0.949	< 1.000
P V R T	5.151	6	0.858	< 1.000
T x Subjects within PVR	183.820	122	1.507	---
Item (I)	316.254	1	316.254	96.836*
P I	0.411	1	0.411	< 1.000
V I	20.375	1	20.375	6.239*
R I	10.946	3	3.649	1.117
P V I	4.603	1	4.603	1.409
P R I	13.986	3	4.662	1.427
V R I	10.280	3	3.427	1.049
P V R I	4.130	3	1.377	< 1.000
I x Subjects within PVR	199.219	61	3.266	---
I T	1.031	2	0.516	< 1.000
P I T	0.029	2	0.015	< 1.000
V I T	0.474	2	0.237	< 1.000
R I T	9.488	6	1.581	1.655
P V I T	3.001	2	1.500	1.570
P R I T	8.848	6	1.475	1.543
V R I T	0.855	6	0.142	< 1.000
P V R I T	2.895	6	0.482	< 1.000
I T x Subjects within PVR	116.598	122	0.956	---
Total	2611.948	461	---	---

* $p < .05$

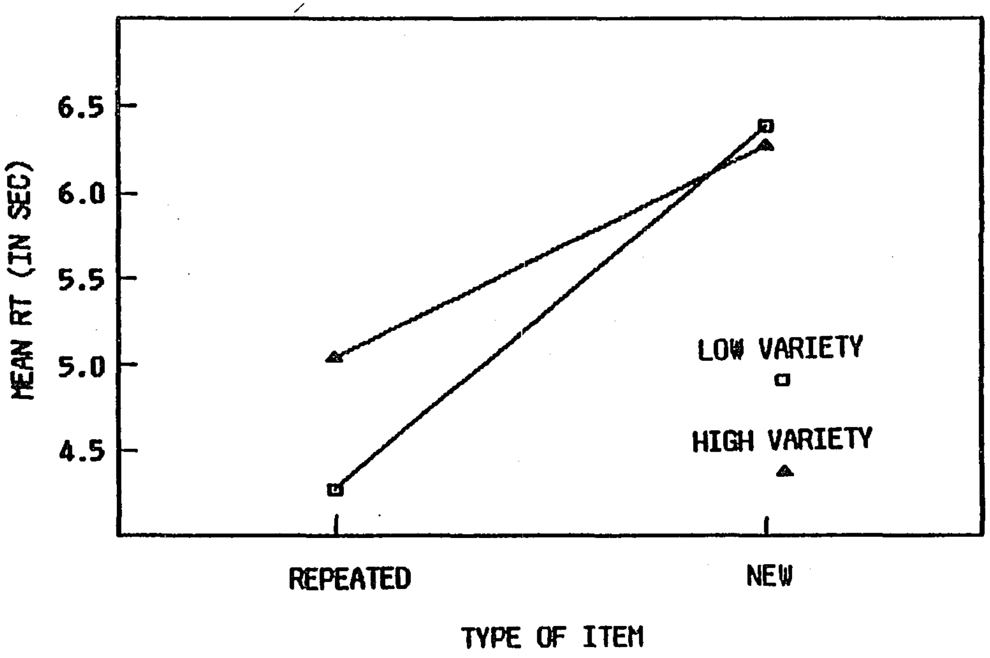

Figure 17. Mean Reaction Time (RT; in sec) for Repeated and New Math Problems in the Retention Session After Low- and High-Variety Practice

Table 15

Summary of Analysis of Variance for Math Percentage of Errors in the Retention Transfer Session

Source of Variation	Sum of Squares	*df*	Mean Square	*F*
Practice Mode (P)	1011.502	1	1011.502	1.095
Variety (V)	81.084	1	81.084	< 1.000
Retention (R)	2315.447	3	771.816	< 1.000
P V	6280.697	1	6280.697	6.800*
P R	1698.057	3	566.019	< 1.000
V R	1549.992	3	516.664	< 1.000
P V R	6967.242	3	2322.414	2.514
Subjects within PVR	56340.372	61	923.613	---
Test Mode (T)	754.358	2	377.179	1.740
P T	339.755	2	169.877	< 1.000
V T	244.731	2	122.366	< 1.000
R T	2740.172	6	456.695	2.107
P V T	608.337	2	304.169	1.403
P R T	1250.205	6	208.368	< 1.000
V R T	601.778	6	100.296	< 1.000
P V R T	642.134	6	107.022	< 1.000
T x Subjects within PVR	26443.928	122	216.754	---
Item (I)	4849.243	1	4849.243	16.604*
P I	139.153	1	139.153	< 1.000
V I	1538.110	1	1538.110	5.267*
R I	724.713	3	241.571	< 1.000
P V I	0.152	1	0.152	< 1.000
P R I	5.283	3	1.761	< 1.000
V R I	951.600	3	317.200	1.086
P V R I	645.899	3	215.300	< 1.000
I x Subjects within PVR	17815.315	61	292.054	---
I T	222.885	2	111.442	< 1.000
P I T	339.818	2	169.909	< 1.000
V I T	278.368	2	139.184	< 1.000
R I T	1096.287	6	182.715	1.061
P V I T	70.547	2	35.273	< 1.000
P R I T	1314.623	6	219.104	1.273
V R I T	158.785	6	26.464	< 1.000
P V R I T	142.426	6	23.738	< 1.000
I T x Subjects within PVR	21005.562	122	172.177	---
Total	161168.560	461	---	---

within *P*, which were in opposite directions. Comparisons indicated that there was no significant difference between any pair of means.

The *V* X *I* interaction, depicted in Figure 18, is similar to the pattern obtained for the RT results. Scheffe tests conducted between the types of items within each level of variety indicated new problems were performed significantly less accurately than old problems after LV practice, $F(3,458) = 6.79$, but not after HV practice, $F(3,458) < 1.00$. This pattern suggests that the LV groups found new math problems to be more difficult to solve than repeated ones.

Math correct response interval analysis. Table 16 summarizes the descriptive statistics for the math CRI. The average CRI across all groups and conditions was 7.04 sec (*SD* = 3.52). Little differential effect was observed as a function of the type of practice. Small changes emerged as a function of the retention interval; CRI increased between one to five days from 6.9 sec to 7.8 sec. Across all between-group factors, the solution times for repeated and new items were about 5.8 sec and 8.3 sec, respectively, and differences between test modes amounted to about 0.5 sec.

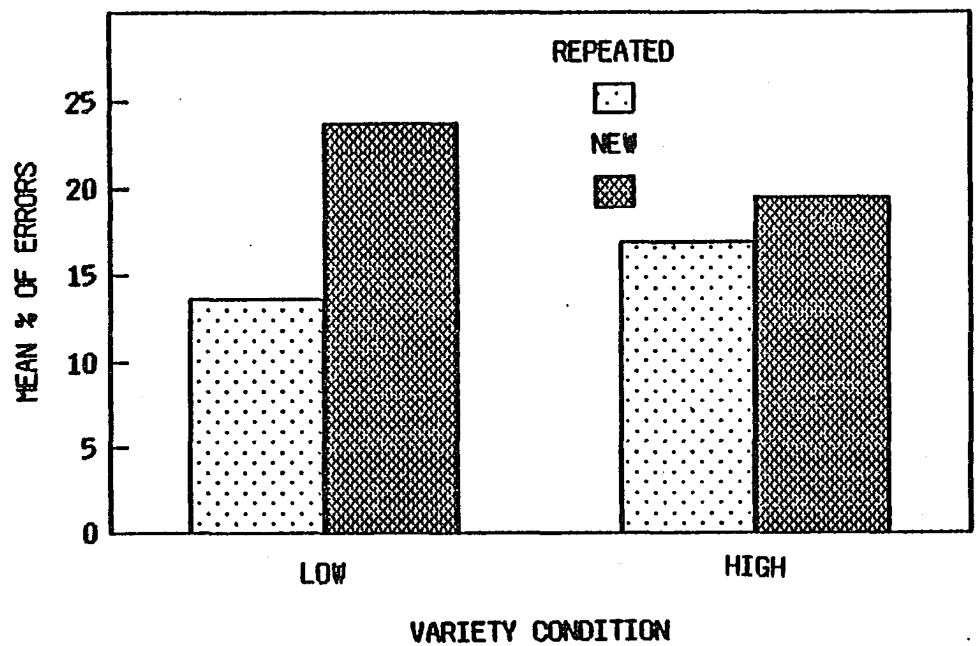

Figure 18. Mean Percentage of Errors for Repeated and New Math Problems in the Retention Transfer After Low- and High-Variety Practice

Table 16

Mean Correct Response Interval (CRI; in sec) for New and Repeated Math Problems in the Retention Transfer Session

Practice Conditions			Type of Item			Difference
Mode	Variety	*n*	New (N)	Repeated (R)	*M*	(N - R)
Single	Low	20				
M time			8.25	5.07	6.66	3.18
Single	High	19				
M time			8.19	6.20	7.20	1.99
Dual	Low	18				
M time			8.68	4.94	6.81	3.74
Dual	High	18				
M time			8.12	6.88	7.50	1.24
Total *M* time		75	8.31	5.76	7.04	2.55

The results of the ANOVA conducted on the math log CRI data are presented in Table 17. As in the RT analysis the effect for items was significant, as was the _V_ X _I_ interaction. Figure 19 displays the _V_ X _I_ interaction. Differences between old and new math items were significant within both the LV, $F(3,446)$ = 25.36, and the HV conditions, $F(3,446) = 5.72$. In addition, repeated problems were solved significantly faster by the LV than the HV group, $F(3,446) = 6.14$.

Trigram reaction time and error analysis. Mean trigram RT and percentage of errors measures are presented in Table 18. Across all study conditions the mean solution time for trigrams was 4.21 sec (_SD_ = 1.84). RT increased as a function of the length of the retention interval from 3.5 to 4.7 secs. Old items were performed about 0.4 sec faster than new items. Within test modes RTs increased from 3.7 to 4.6 sec as the number of concurrent tasks increased. Mean percentage of errors across groups averaged 7% (_SD_ = 11). Differences were small as a function both between-group and within-subject variables. Across retention intervals, errors decreased from 9% to 6%. Repeated items were solved about 1.5% more accurately than new ones across groups and test modes. The differences between test modes across other factors amounted to less than .5%.

Table 17

Summary of Analysis of Variance for Math log CRI in the Retention Transfer Session

Source of Variation	Sum of Squares	df	Mean Square	F
Practice Mode (P)	0.430	1	0.430	< 1.000
Variety (V)	2.536	1	2.536	1.948
Retention (R)	2.495	3	0.832	< 1.000
P V	0.070	1	0.070	< 1.000
P R	2.244	3	0.748	< 1.000
V R	0.848	3	0.283	< 1.000
P V R	1.357	3	0.452	< 1.000
Subjects within PVR	76.782	59	1.301	---
Test Mode (T)	0.274	2	0.137	< 1.000
P T	0.221	2	0.111	< 1.000
V T	0.000	2	0.000	< 1.000
R T	0.485	6	0.081	< 1.000
P V T	0.348	2	0.174	1.157
P R T	1.512	6	0.252	1.677
V R T	0.407	6	0.068	< 1.000
P V R T	0.344	6	0.057	< 1.000
T x Subjects within PVR	17.725	118	0.150	---
Item (I)	27.017	1	27.017	79.389*
P I	0.049	1	0.049	< 1.000
V I	3.261	1	3.261	9.583*
R I	1.218	3	0.406	1.193
P V I	0.273	1	0.273	< 1.000
P R I	0.852	3	0.284	< 1.000
V R I	0.158	3	0.053	< 1.000
P V R I	0.429	3	0.143	< 1.000
I x Subjects within PVR	20.078	59	0.340	---
I T	0.349	2	0.174	2.484
P I T	0.061	2	0.031	< 1.000
V I T	0.137	2	0.068	< 1.000
R I T	0.870	6	0.145	2.065
P V I T	0.110	2	0.055	< 1.000
P R I T	0.899	6	0.150	2.132
V R I T	0.105	6	0.017	< 1.000
P V R I T	0.260	6	0.043	< 1.000
I T x Subjects within PVR	8.288	118	0.070	---
Total	171.492	449	---	---

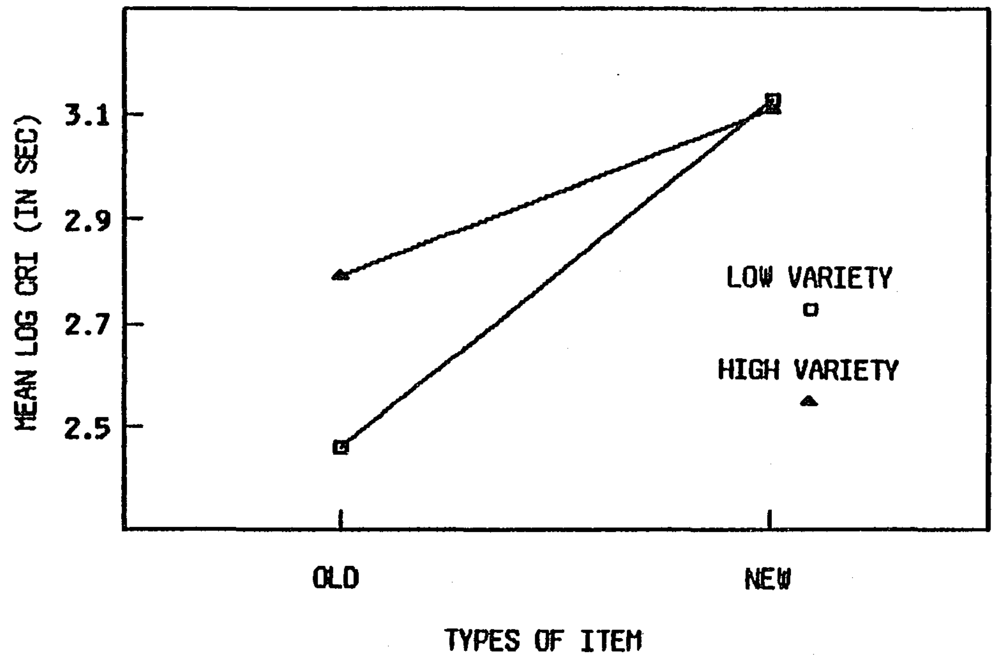

Figure 19. Mean log CRI (in sec) for Repeated and New Math Problems in the Retention Session After Low- and High-Variety Practice

Table 18

Mean Reaction Time (RT; in sec) and Errors for New and Repeated Trigrams in the Retention Session

Practice Conditions			Type of Item			Difference
Mode	Variety	n	New (N)	Repeated (R)	M	(N - R)
Single	Low	20				
M time			4.49	4.14	4.32	0.35
% error			8	7	8	1
Single	High	20				
M time			4.08	3.68	3.88	0.40
% error			5	4	5	1
Dual	Low	19				
M time			4.76	3.79	4.27	0.97
% error			9	6	8	3
Dual	High	20				
M time			4.36	4.35	4.36	0.01
% error			9	7	8	2
Total		79				
M time			4.42	3.99	4.21	0.42
% error			8	6	7	2

Table 19 summarizes the results of the ANOVA conducted on the trigram RT data. Main effects for Items and Test modes were significant. In addition the *V* X *I*, *P* X *V* X *T* and *P* X *V* X *I* interactions reached significance.

Figure 20 displays the joint effects of *I* and *T* (the interaction was not significant). Solution times for new trigrams were significantly slower than for old trigrams across all modes. With respect to test mode, the differences in RT between single-task and the multiple-task conditions was highly significant, $F(2,471) = 16.90$ and $F(2,471) = 33.49$ for the dual- and triple-task conditions, respectively. The multiple-task conditions did not differ significantly from each other, $F(2,471) = 3.02$.

The *V* X *I* interaction is shown in Figure 21. Differences between new and repeated trigrams were substantially larger for LV than HV groups. These differences were significant after LV practice, $F(3,470) = 8.96$, but not after HV practice, $F(3,470) < 1.00$. In addition, solution time for new problems between levels of variety was significant, $F(3,470) = 3.51$.

Table 19

Summary of Analysis of Variance for Trigram RT in the Retention Transfer Session

Source of Variation	Sum of Squares	df	Mean Square	F
Practice Mode (P)	3.067	1	3.067	< 1.000
Variety (V)	1.828	1	1.828	< 1.000
Retention (R)	106.772	3	35.591	2.402
P V	11.808	1	11.808	< 1.000
P R	103.818	3	34.606	2.336
V R	56.244	3	18.748	1.265
P V R	53.730	3	17.910	1.209
Subjects within PVR	933.488	63	14.817	---
Test Mode (T)	58.536	2	29.268	35.133*
P T	0.459	2	0.229	< 1.000
V T	0.765	2	0.382	< 1.000
R T	3.462	6	0.577	< 1.000
P V T	9.675	2	4.837	5.807*
P R T	3.227	6	0.538	< 1.000
V R T	2.623	6	0.437	< 1.000
P V R T	4.259	6	0.710	< 1.000
T x Subjects within PVR	104.965	126	0.833	---
Item (I)	21.129	1	21.129	22.889*
P I	0.318	1	0.318	< 1.000
V I	5.691	1	5.691	6.165*
R I	2.951	3	0.984	1.066
P V I	6.832	1	6.832	7.401*
P R I	1.553	3	0.518	< 1.000
V R I	2.234	3	0.745	< 1.000
P V R I	2.516	3	0.839	< 1.000
I x Subjects within PVR	58.156	63	0.923	---
I T	1.563	2	0.781	1.601
P I T	0.868	2	0.434	< 1.000
V I T	0.790	2	0.395	< 1.000
R I T	2.747	6	0.458	< 1.000
P V I T	1.763	2	0.881	1.806
P R I T	2.290	6	0.382	< 1.000
V R I T	2.438	6	0.406	< 1.000
P V R I T	3.676	6	0.613	1.255
I T x Subjects within PVR	61.500	126	0.488	---
Total	1637.741	473	---	---

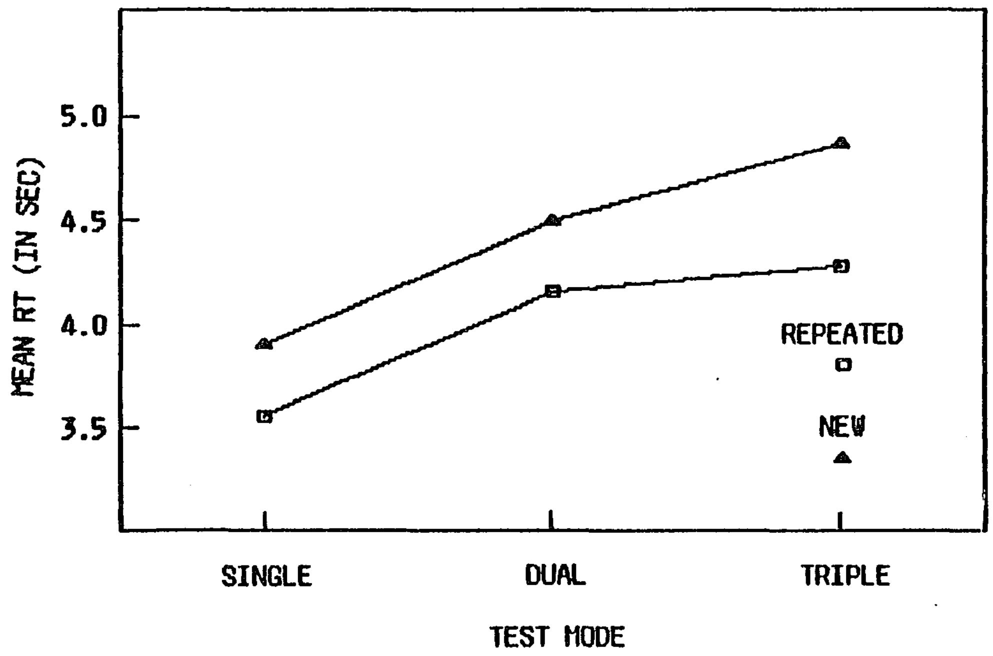

Figure 20. Mean Reaction Time (RT; in sec) for Repeated and New Trigrams in the Retention Session as a Function of Test Mode

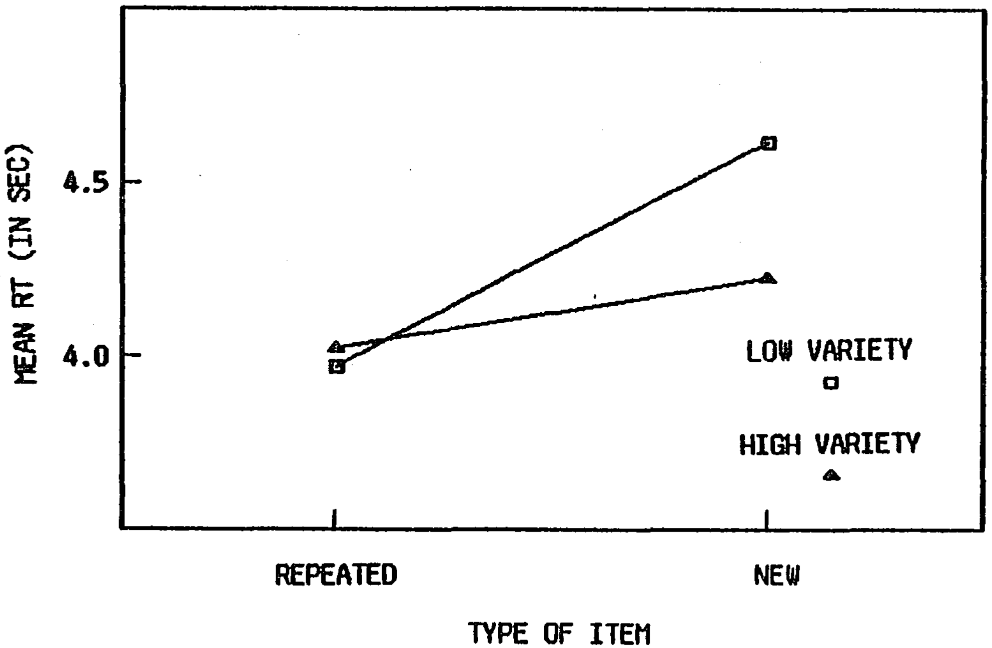

Figure 21. Mean Reaction Time (RT; in sec) for Repeated and New Trigrams in the Retention Session After Low- and High-Variety Practice

The combined effects of practice mode and variety on trigram retention were observed in the two triple interactions, P X V X I and P X V X T (Figures 22 and 23, respectively). As shown by the P X V X I interaction depicted in Figure 22, the influence of variety on solution time for repeated and new items apparently occurred only after dual-task practice. This pattern reflects the trigram RT results of the immediate transfer session (Figure 12) although the differences between SP groups appeared larger during retention. Within the DP groups, the expected pattern was observed; large item differences were obtained after LV, and negligible differences occurred after HV practice. Furthermore, the comparison between the SP-LV and DP-LV groups suggests that the difference between new and repeated trigrams was substantially larger in the DP group.

To separate these complex effects, the interactions between the practice variables with item and mode were examined separately at each level of V and P. Specifically, the V X I X T ANOVA's at each level of P, and the P X I X T ANOVA's at each level of V, were conducted. The results of the analyses are summarized in Table 20. The main effects of the practice variables were not significant in any of the four analyses, while the within-subject factors I and T

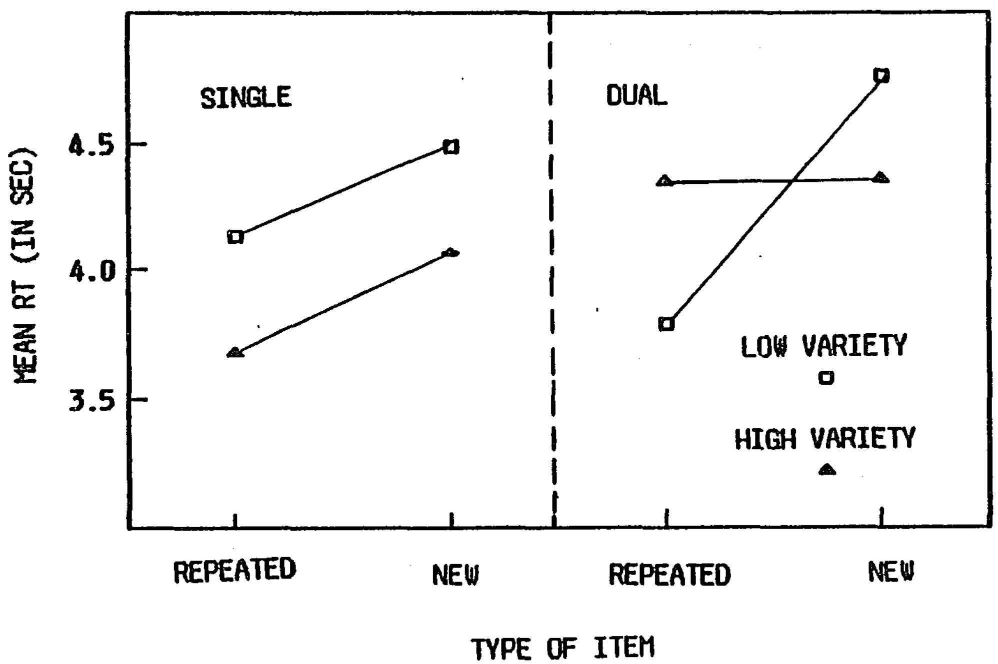

Figure 22. Mean Reaction Time (RT; in sec) for Repeated and New Trigrams in the Retention Session as a Joint Function of Practice Mode and Variety

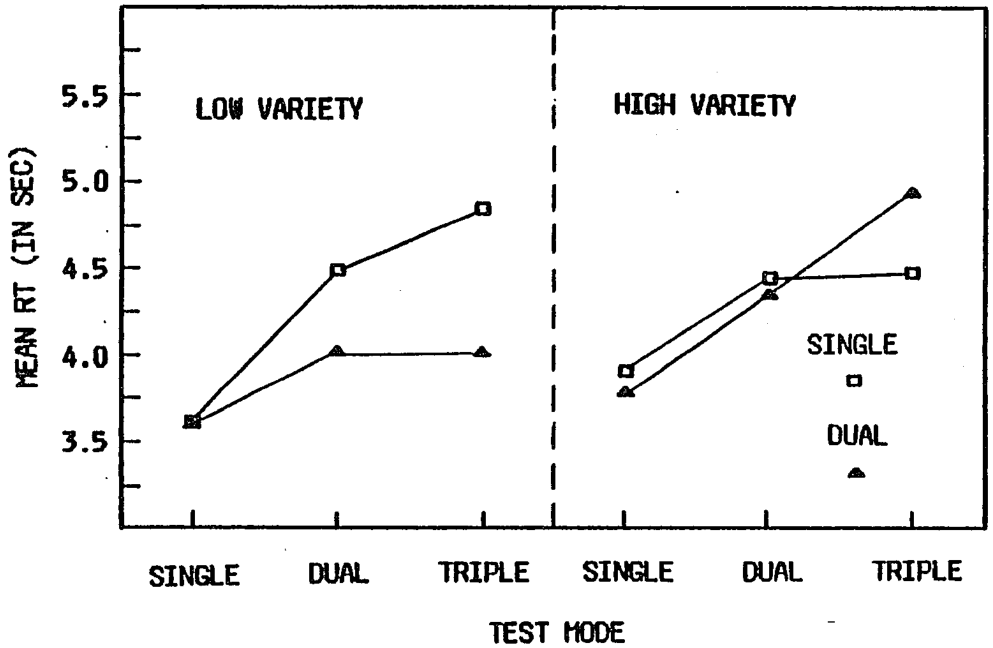

Figure 23. Mean Reaction Time (RT; in sec) for Trigram Performance in the Retention Session after Single- and Dual-Task Practice as a Joint Function of Variety of Practice and Test Mode

Table 20

Summary of ANOVA's Breaking Down the Complex Interaction for Trigram RT in the Retention Transfer Session

Source of Variation	Within SP		Within DP	
	MS	F	MS	F
Variety (V)	11.642	1.32	0.373	< 1.00
Test Mode (T)	14.674	23.68*	14.851	15.36*
Item (I)	8.258	16.31*	14.135	10.96*
V x T	3.265	5.27*	2.051	2.12
V x I	0.026	< 1.00	13.295	10.31*

Source of Variation	Within LV		Within HV	
	MS	F	MS	F
Practice Mode (P)	0.109	< 1.00	13.667	1.05
Test Mode (T)	17.155	14.89*	12.507	28.49*
Item (I)	25.412	20.85*	2.483	4.32*
P x T	2.029	1.76	3.090	7.04*
P x I	5.593	4.59*	2.134	3.71

* p <.05

were significant in each test.

The pattern of interactions is most informative regarding the differences between and within groups. Within DP, the *V* X *I* interaction was significant, $F(1,37) = 10.31$; within LV, the *P* X *I* interaction also reached significance, $F(1,37) = 4.59$. Scheffe tests indicated that the differences between new and repeated items was significant after dual-task practice, $F(3,230) = 7.31$, but not after single-task practice, $F(3,230) = 1.01$. For both interactions, these effects were attributable to the differences between the DP-LV repeated-item mean solution time and all other means.

In terms of the interactive effects of practice variables with test mode, the *P* X *V* X *T* interaction shown in Figure 23 suggests that the combinations of concurrent-task, low-variety practice and single-task high variety both resulted in the most effective performance of the trigram task at multiple-task levels. Comparing between levels of *P* the performances in the multiple-task conditions also appear superior for the SP-HV vis-a-vis the SP-LV group, and the DP-LV vis-a-vis the DP-HV group. The significance of these interactions is reflected by the *P* X *T* effect, summarized in Table 20. The interaction reached significance in the analysis within HV groups, $F(2,76)$

= 7.04. Scheffe tests confirmed that the between-groups difference at the triple-task mode was significant, $F(5,234) = 7.74$, indicating that the SP-HV group solved trigrams during the retention session faster than the DP-HV groups in that condition. Furthermore, within the SP-HV, none of the comparisons between test modes reached signficance, whereas in the DP-HV group, all differences were significant. Within LV, the size of the within-subject MS-error, which was attributable mainly to the DP-LV within-cell variance, obscured the effect, $F(2,74) = 1.76$, $p < .18$.

To explore the relationship between the practice and test conditions further, subjects were grouped above or below the median on the basis of their difference scores between old and new trigrams. A series of 2 X 2 chi-square tests were conducted between median group and variety practice condition within each level of P. Results indicated that within the SP group, variety was independent of median with respect to both dual-task, $\chi^2 < 1.00$, and triple-task test performances, $\chi^2 = 1.37$. In the single-task test condition, the Chi-square almost reached significance, $\chi^2 = 3.60$. After DP practice, there was a significant relationship between median group and variety at both the dual-, $\chi^2 = 5.11$, and the triple-task test mode level, $\chi^2 = 5.55$. At the single-task test mode condition, the relationship was nearly significant, χ^2 = 3.09. These results are consistent with the interpretation that providing dual-task training and repetition of trigrams both were important in the retention of skills required for differentiating new and repeated items during the multiple-task transfer conditions. Low variety alone was not sufficient.

The summary of the ANOVA conducted on the accuracy measure, summarized in Table 21, indicated only that there was a significant effect for Item.

Trigram correct response interval analysis. The descriptive statistics for trigram CRI are provided in Table 22. Except for their absolute values, which reflect the adjustment for incorrect answers, the trigram CRI is almost identical to the RT measure just reported. Across all conditions mean trigram CRI during the retention session was 4.57 (SD = 2.22).

Table 23 summarizes the results of the ANOVA performed on the trigram log CRI. A main effect for R was significant as was its interaction with practice mode (P X R). As evidenced in the P X R interaction depicted by Figure 24, CRI latency tended to increase across the five-day retention interval. Across all other factors, the linear regression of CRI from one to

Table 21

Summary of Analysis of Variance for Tri-gram Percentage of Errors in the Retention Transfer Session

Source of Variation	Sum of Squares	df	Mean Square	F
Practice Mode (P)	399.784	1	399.784	1.329
Variety (V)	335.537	1	335.537	1.116
Retention (R)	1119.781	3	373.260	1.241
P V	230.132	1	230.132	< 1.000
P R	764.919	3	254.973	< 1.000
V R	939.611	3	313.204	1.041
P V R	543.667	3	181.222	< 1.000
Subjects within PVR	19249.744	64	300.777	---
Test Mode (T)	2.778	2	1.389	< 1.000
P T	100.503	2	50.251	< 1.000
V T	70.121	2	35.060	< 1.000
R T	769.152	6	128.192	1.337
P V T	108.490	2	54.245	0.566
P R T	1228.939	6	204.823	2.136
V R T	569.835	6	94.972	< 1.000
P V R T	338.483	6	56.414	< 1.000
T x Subjects within PVR	12274.890	128	95.898	---
Item (I)	518.711	1	518.711	5.828
P I	189.631	1	189.631	2.131
V I	23.426	1	23.426	< 1.000
R I	248.939	3	82.980	< 1.000
P V I	42.340	1	42.340	< 1.000
P R I	110.520	3	36.840	< 1.000
V R I	511.512	3	170.504	1.916
P V R I	264.428	3	88.143	< 1.000
I x Subjects within PVR	5696.230	64	89.004	---
I T	50.549	2	25.275	< 1.000
P I T	152.166	2	76.083	< 1.000
V I T	148.792	2	74.396	< 1.000
R I T	298.080	6	49.680	< 1.000
P V I T	93.799	2	46.899	< 1.000
P R I T	369.784	6	61.631	< 1.000
V R I T	604.519	6	100.753	< 1.000
P V R I T	285.331	6	47.555	< 1.000
I T x Subjects within PVR	13934.807	128	108.866	---
Total	62589.930	479	---	---

Table 22

Mean Correct Response Interval (CRI; in sec) for New and Repeated Trigrams in the Retention Transfer Session

Practice Conditions			Type of Item			Difference
Mode	Variety	*n*	New (N)	Repeated (R)	*M*	(N - R)
Single	Low	20				
M time			4.86	4.50	4.69	0.36
Single	High	20				
M time			4.33	3.85	4.09	0.48
Dual	Low	19				
M time			5.47	4.13	4.80	1.34
Dual	High	20				
M time			4.80	4.63	4.72	0.17
Total *M* time		79	4.86	4.28	4.57	0.58

Table 23

Summary of Analysis of Variance for Trigram log CRI in the Retention Transfer Session

Source of Variation	Sum of Squares	df	Mean Square	F
Practice Mode (P)	0.006	1	0.006	< 1.000
Variety (V)	0.037	1	0.037	< 1.000
Retention (R)	9.195	3	3.065	2.871*
P V	1.489	1	1.489	1.395
P R	11.157	3	3.719	3.483*
V R	3.285	3	1.095	1.026
P V R	5.430	3	1.810	1.695
Subjects within PVR	67.262	63	1.068	---
Test Mode (T)	4.427	2	2.214	32.434*
P T	0.148	2	0.074	1.083
V T	0.128	2	0.064	< 1.000
R T	0.047	6	0.008	< 1.000
P V T	0.598	2	0.299	4.380*
P R T	0.524	6	0.087	1.279
V R T	0.220	6	0.037	< 1.000
P V R T	0.402	6	0.067	< 1.000
T x Subjects within PVR	8.600	126	0.068	---
Item (I)	2.097	1	2.097	35.190*
P I	0.074	1	0.074	1.239
V I	0.276	1	0.276	4.634*
R I	0.093	3	0.031	< 1.000
P V I	0.555	1	0.555	9.322*
P R I	0.101	3	0.034	< 1.000
V R I	0.377	3	0.126	2.112
P V R I	0.053	3	0.018	< 1.000
I x Subjects within PVR	3.753	63	0.060	---
I T	0.041	2	0.021	< 1.000
P I T	0.083	2	0.042	< 1.000
V I T	0.003	2	0.001	< 1.000
R I T	0.330	6	0.055	1.184
P V I T	0.198	2	0.099	2.135
P R I T	0.234	6	0.039	< 1.000
V R I T	0.588	6	0.098	2.109
P V R I T	0.235	6	0.039	< 1.000
I T x Subjects within PVR	5.854	126	0.046	---
Total	127.900	473	---	---

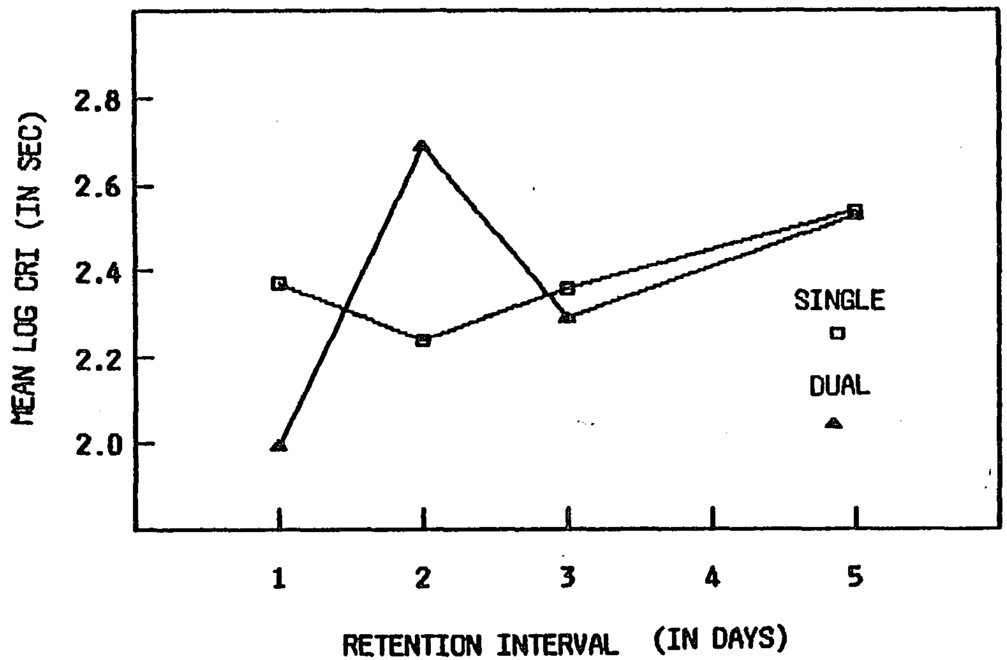

Figure 24. Mean log CRI (in sec.) for Trigram Performance After Single- and Dual-Practice as a Function of the Retention Interval

five days was statistically significant, $F(1,472) = 18.57$, $MS = 4.76$. The least-squares line of best fit describing the relationship was log CRI = 2.19 + .068RI.

The forms of the other main effects and interactions for the trigram CRI measure closely resembled the patterns of RT effects discussed earlier. The main effects of items and test modes were significant, as was the $V \times I$ interaction. In addition, the two training variables P and V interacted jointly with Items and Test Modes (e.g., $P \times V \times I$; $P \times V \times T$).

With regard to the main effects of Item, the results were consistent with prior analyses in that the solution times for new trigrams were significantly longer than for old trigrams, $F(1,63) = 35.19$. In terms of the raw scores, subjects took about 0.6 sec longer to solve new problems than old ones. With respect to test mode, mean CRI was faster in the single-task than in the dual-task condition, $F(2,471) = 17.93$, and the triple-task condition, $F(2,471) = 29.20$. The multiple-task conditions did not differ from each other.

Practice mode and variety interacted with both items and test modes. Figure 25 depicts the V X I interaction, which is almost identical with the form of the RT interaction shown earlier. Differences in solution times for the old and new problems were significant for LV, $F(3,470) = 10.91$, but not for the HV groups, $F(3,470) = 2.42$. The P X V X I interaction (Figure 26) further indicated that the combined effects of V and I were moderated by practice mode. To explore the triple interaction further, separate ANOVA's were conducted within each practice mode. The results of the analyses are presented in Table 24. For the SP groups, the V X I interaction was not significant, $F(1,38) < 1.0$, $MS = .025$. For the analysis of DP groups, the interaction was significant, $F(1,37) = 9.69$, $MS = .848$. Scheffe tests indicated that the CRI's between the old and new trigrams were significant in the LV, $F(3,230) = 8.65$, but not the HV group, $F(3,230) < 1.00$.

The P X V X T interaction for trigram retention is graphically depicted in Figure 27. As was the case in the RT analyses, the level of variety provided during practice affected the pattern of trigram retention for the DP groups across test-mode condition. Specifically, after LV practice SP and DP groups were equivalent at the single-task level of test mode; at the multiple-task test modes the DP group was somewhat

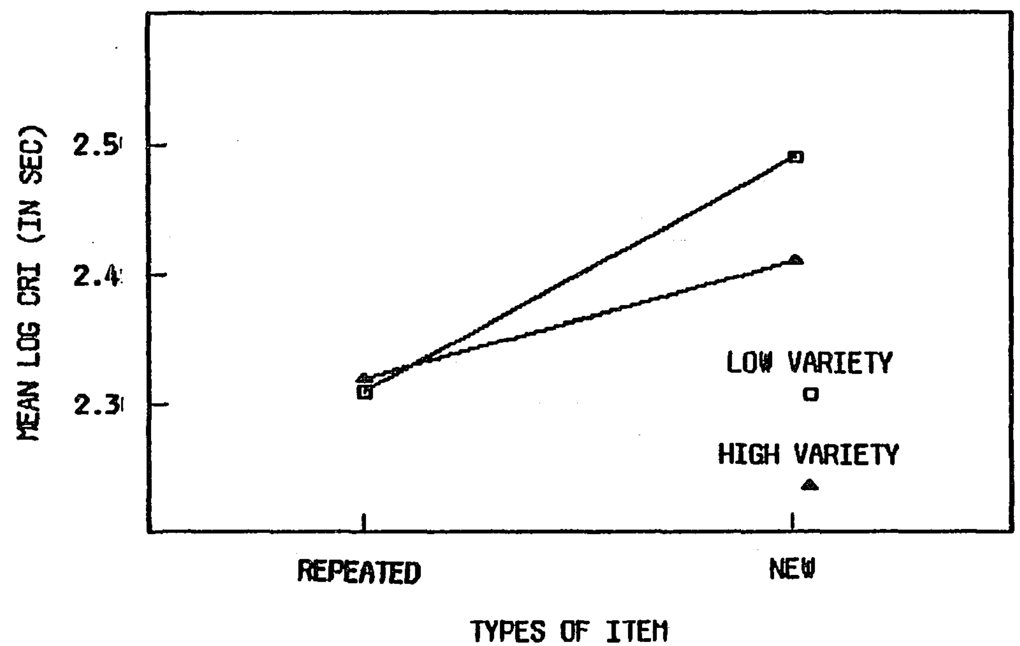

Figure 25. Mean log CRI (in sec) for Repeated and New Trigrams in the Retention Session After Low- and High-Variety Practice

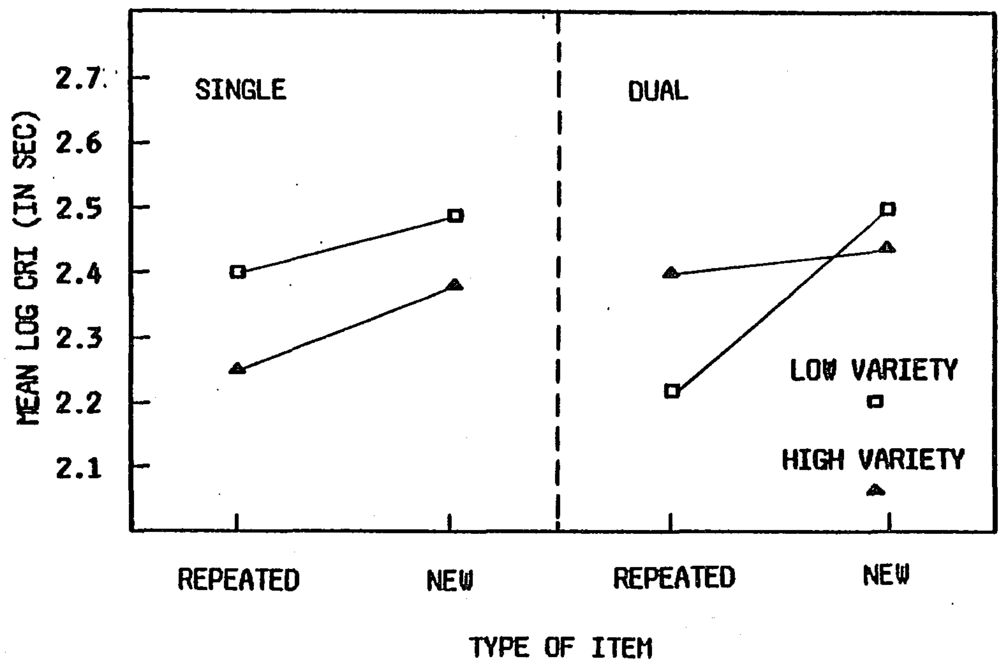

Figure 26. Mean log CRI (in sec) for Repeated and New Trigrams in the Retention Session As a Joint Function of Practice Mode and Variety

Table 24

Summary of ANOVA's Breaking Down the Complex Interaction for Trigram log CRI in the Retention Transfer Session

Source of Variation	Within SP MS	Within SP F	Within DP MS	Within DP F
Variety (V)	1.012	1.66	0.217	<1.00
Test Mode (T)	0.976	17.51*	1.285	17.12*
Item (I)	0.703	23.76*	1.529	17.48*
V x T	0.229	4.11*	0.149	1.98
V x I	0.025	<1.00	0.848	9.69*

Source of Variation	Within LV MS	Within LV F	Within HV MS	Within HV F
Practice Mode (P)	0.427	<1.00	0.667	<1.00
Test Mode (T)	1.394	18.03*	0.861	16.08*
Item (I)	2.003	25.41*	0.432	11.36*
P x T	0.645	<1.00	0.319	5.95*
P x I	0.551	6.99*	0.114	2.99

* p <.05

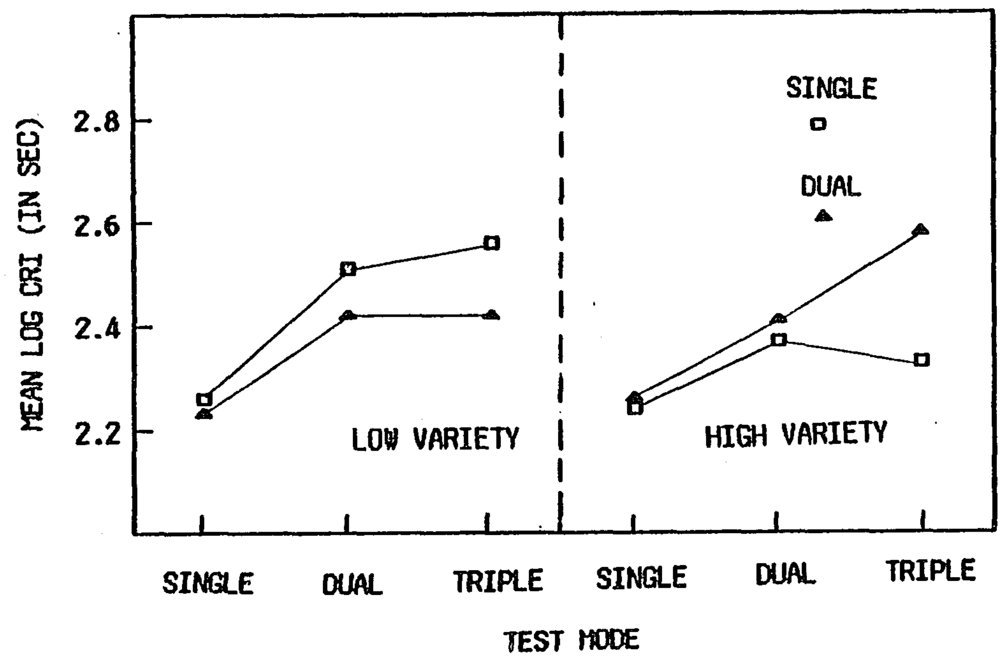

Figure 27. Mean log CRI (in sec) for Trigram Performance in the Retention Session After Single- and Dual-Task Practice as a Joint Function of Variety of Practice and Test Mode

faster. In contrast, after HV practice, both single and dual-task performance was essentially equal between the SP and DP groups, while triple-task performance was slower for the DP group. ANOVA's were conducted within each level of *V*, focusing on the *P* X *T* interaction (see Table 24). The results indicated that there was a significant interaction at the level of HV, $F(2,76) = 5.95$, $MS = .319$, but not at the level of LV, $F(2,74) < 1.00$, $MS = .064$. Scheffe tests further indicated that the HV groups differed only at the triple-task level, $F(5,234) = 4.68$.

DISCUSSION

In complex cognitive performances there are potentially many alternative modes of action, or performance strategies, for fulfilling task demands. Strategies, as discussed in the introduction and below, are considered here to be subject-controlled operations and procedures that are directly related to the cognitive skills or processes used to perform tasks. More specifically, at the level considered here, they are defined as the use of different mixes of the cognitive skills used in task performance. In the area of complex performance, many approaches have been used to understand the nature and antecedents of skilled performance, including the identification of ability structures (Fleishman, 1972; Fleishman & Hemple, 1954; Jones, 1962); the contribution of part-task training to whole-task performance (Adams and Hufford, 1962; Damos and Wickens, 1980; Irion, 1966; Rieck et al., 1980); study of the acquisition process in motor skills (Bilodeau, 1966; Newell, 1981; Schmidt, 1975), and in problem-solving (Davis, 1966; Glaser, 1982; Harlow, 1949). However, little attention has been applied to the role of performance strategies as mediators of skilled performance.

The present investigation was concerned with the utilization and maintenance of performance strategies in solving two types of problems, mental arithmetic and trigrams. Although the specific kinds of mental operations required to perform these tasks are quite different, the approach taken here assumed that the performance of both tasks could be characterized by two domains of skills. These two skills were: (a) operational skills, which include procedural skills (e.g., Kolers, 1973) and declarative skills (Rumulhart & Norman, 1981); and (b) time-sharing skills, which involve the ability perform more than one task within the same time frame. These latter skills are also referred to as attention management (North & Gopher, 1976) or resource allocation skills (Wickens et al., 1981).

Operational skills were assumed to be related to the type of memory encoding employed in learning to solve problems. All of the problems of the sort used here could be solved by performing learned operations or procedures, that is, by mentally working through the problem-solving steps learned during acquisition (Kolers, 1973, 1975). All of the subjects practiced procedural skills during at least the beginning of the acquisition phase, before specific items were encoded. The cognitive effort required for solving problems in this fashion was assumed to be relatively high, since the two tasks possessed a moderate degree of complexity. Declarative skills (e.g., Rumulhart & Norman, 1981) could also be applied to the solutions of problems presented here. During acquisition the subjects in the low variety condition were presented repeatedly a subset of five math and five trigram problems. These old or repeated problems could be encoded in memory as specific elements of declarative knowledge or skill, analagous to the specific instances of demand which an operater faces repeatedly in a complex system. Thus, during the transfer session, the correct solutions for these problems could be found by retrieving them from memory. The cognitive demand that was involved in using declarative skills for solving the problems was considered to be substantially less than that required in solving problems computationally.

During the transfer phase of this study, when subjects were faced with both old and new problems, procedural and declarative skills were postulated to form the basis of two classes of performance strategies, unitary and dual. Subjects could use a unitary strategy by applying procedural knowledge to the solution of all problems. This strategy would lead to no differences in solution times for old and new problems. In the dual strategy, the subjects would use a combination of both procedural and declarative skills, thereby retrieving old problems while computing the answers to new ones. It is assumed that retrieval would be a preferred process in that it would have been initiated first and followed by a mental computation only if the memory search was unsuccessful. (Since both new and repeated problems were presented during transfer, retrieval alone was not a viable strategy.) A dual-process strategy would presumably reduce the amount of time that was necessary to respond to old problems but also increase the amount of time to respond to new ones.

The purpose of manipulating the degree of variety during the acquisition, was to influence the development of operational skills, and hence, the adoption of different strategies. Specifically, it was hypothesized that a low variety of problems during practice would result in the use of both procedural and declarative skills, while a high variety of problems in practice would result in the use of procedural skills.

The manipulation of practice mode involved a variation in the extent to which concurrent-task management skills contributed to performance of a complex task. Thus, practice mode was not assumed to be directly related to the formation of strategies. It was hypothesized that the best transfer would occur between the most similar practice and test phases, as many prior investigations have found (see, for example, Rieck et al., 1980). In addition, to the extent that the cognitive skills learned here form the basis for utilizing performance strategies, it can be inferred that the greatest transfer of strategies would occur in test conditions that were most similar to the practice conditions.

This research focused on several questions related to the selection and use of the two types of strategies discussed above. Underlying these was the broader question of whether the pattern of results would support an explanation that the groups trained under different conditions would use different strategies during the transfer tests. During the immediate transfer session the analysis focused on the main effects of the practice variables-- practice mode and variety, and their interactions with the test conditions-- on solution times and errors. During the retention transfer session, a similar analysis examined the maintenance of procedural and declarative skills, and the stability of strategies, as a function of the retention interval.

Immediate Transfer Effects

Analysis of the immediate transfer session examined the development of operational and concurrent-task skills and the utilization of performance strategies in the complex transfer session. The main findings of the analysis of the immediate session, to be discussed below, suggested that (a) the variety of problems solved during practice resulted in the learning of different operational skills; (b) dual-task practice resulted in better concurrent-task skill acquisition; and (c) variety and dual-task practice jointly contributed to the adoption of performance strategies.

The results obtained with both the math and the trigram task consistently supported the notion that the variety of problems during practice influenced the development of declarative and procedural skills, as well as the selection of performance strategies. The results also indicated that the two practice variables interacted in their influence on performance. Across all of the test conditions used in the analysis, however, there was no indication that either of the practice variables, or their joint occurrence, led to better (faster) performance.

Variety and operational-skills acquisition. One of the assumptions of the study was that the amount of variety among the problems presented during practice would affect the extent to which subjects would encode specific items or the computational operations necessary to solve the problems. Evidence that these skills were distinct is found in the difference in solution times needed to solve the problems. As has been discussed earlier, retrieving answers from memory was expected to require much less time than working through the computations.

The results of the interactions between the variety of practice and the type of item solved during transfer were used to investigate the extent to which different skills were developed. Specifically, procedural skills were expected to be learned after practice with a large variety of problems, while declarative skills were expected to emerge after repeated presentations of a constrained problem set. In terms of the predicted interaction between variety and item, after low-variety practice, large differences between old and new problems were expected, while after high-variety practice, no difference between the item types was expected. Between-group differences were predicted for repeated items because of the assumption that subjects would apply different types of skills.

For new items, differences between groups was also predicted, because subjects in the high-variety group had many more new problems to solve and, therefore, should be able to acquire greater procedural skill.

Results of the analyses of both tasks indicated that there was a significant interaction between variety and item. Practice with a small number of items resulted in significantly faster solution times for repeated than new items. Furthermore, repeated items were solved more quickly after low than high variety practice. These two findings are both consistent with the notion that a different process was used for obtaining repeated problem solutions by the low variety group.

Although variety has apparently not been investigated before in complex performance, the results of this study are consistent with findings in the cognitive domain. Several investigators (Bransford, et al., 1979; Jacoby & Craik, 1978) have suggested that providing variety of problems during practice helps to overcome encoding specificity. The pattern of between-group differences in the repeated items suggests that variety did result in less specific encoding for the high-variety group, resulting in a reliance on computational operations regardless of the type of problem.

Contrary to expectations, no difference emerged between levels of variety in the solution times of new problems. There are several reasons why these differences may not have obtained. At the outset of practice all subjects solved problems by mental computations and all subjects had the same opportunity to use computations to solve the problems. Furthermore, the transfer phase provided further opportunity for the low variety subjects to learn procedural skills. During the 15-min session, approximately five minutes of time was provided to work on each task, and novel problems were presented about half of that time. Inspection of the acquisition phase indicated that new trigram items were essentially learned after three blocks (12 minutes) under single-task and four blocks (16 minutes) under dual-task performance. For math, the acquisition curves reach asymptotic levels after four (16 minutes) and five (20 minutes) blocks for the two groups trained under single- and dual-task conditions respectively. Thus, sufficient practice may have occurred to learn the procedural skills necessary for computing solutions even when the number of different practiced problems was small.

Concurrent-task skills and processing-load effects. A second focus of the immediate transfer phase was to investigate the contribution of dual-task skills to effective performance under the complex conditions of transfer. Since subjects had practiced solely under single- or dual-task conditions at the outset of the transfer session, the groups were highly different in terms of their skills. Based on a large body of prior research, it was hypothesized that better transfer should occur from practice to the specific transfer conditions which were most similar to practice. For subjects trained under single-task conditions, a significant difference between single- and multiple-task test modes was predicted. No differences in test mode was expected to occur for the dual-task groups, even though a cost, in terms of efficient performance, has been postulated for performing several tasks concurrently (e.g., Navon & Gopher, 1979).

The results of the immediate transfer session were consistent with prior research in the concurrent-task domain. Specifically, these data indicated that (a) increasing the number of tasks does increase processing load regardless of prior training; and (b) providing dual-task training is effective in reducing the effects of processing load.

In regard to processing load, a strong main effect for test mode was obtained with both the math and trigram tasks, across all other factors. In both instances, the time to solve all problems increased from one to three concurrent tasks, indicating that there is a cost for performing tasks concurrently, as others have suggested (Jennings & Chiles, 1977; Navon & Gopher, 1979).

Dual-task practice, however, did ameliorate the effect of time-sharing tasks during the immediate transfer. With respect to between group differences on the trigram task, dual-task practice resulted in single-task performance equivalent to single-task practice and to better dual- and triple-task performances. Within the single-task group multiple-task transfer performance was significantly slower than single-task performance.

On math, the interaction between practice and test mode were observed initially at the level of item. Subsequent analyses indicated that the main effect for test mode (specifically, differences between the single- and dual-task conditions) was significant only after single-task practice. In terms of the percentage of additional time needed to solve math problems in the dual-task vis-a-vis the single-task test condition, subjects required an average of 8% (0.44 sec) after dual-task practice and 21% (1.14 sec) after single-task practice. In the trigram task, the increase amounted to 12% (0.55 sec) after dual-task practice versus 39% (1.55 sec) after single-task practice.

The advantage attributable to dual-task training is even clearer in the pattern of differences between items as a function of practice mode. For the trigram task, the analysis indicated that both dual-task and low-variety practice were necessary for a consistent difference to emerge between old and new problems across the test modes. In this group, the amount of time used to solve old problems showed little change as the number of tasks increased, suggesting that processing load did not greatly influence retrieval processes. In contrast, the solution times for new problems which required procedural skills that were little practiced, increased sharply as load requirements increased.

In the single-task counterparts, declarative skills appeared to be disrupted at all except the single-task level. Analyses within the single-task group indicated that differences between old and new items were obtained only at the single-task level, suggesting that the greater workload of the multiple-task conditions inhibited the use of a dual strategy when there was no prior experience at managing more than one task at a time.

In conclusion, the results confirm the hypothesis that practice provides opportunity to acquire multiple-task skills as well as the skills for the components themselves, while practicing the components provides skills that are specific to the tasks themselves. These results are in agreement with a large body of past research in the area of multiple-task skill development (Alluisi, 1967; Jennings & Chiles, 1977; Rieck et al., 1980; Damos & Wickens, 1980; North & Gopher, 1976). These differences are indicative of the efficacy of practicing the tasks under time-shared conditions. They suggest that training even distinct and functionally different components together will have beneficial effects on later concurrent-task performance.

Strategy utilization. The interaction between the variety of problems solved during practice and the solution times for the types of items during the initial transfer session provided the primary findings for differences in performance strategies. As discussed earlier, the pattern of differences between the groups on old items suggested that they were applying different skills to solving the problems. The difference in solution times for new and old items within the low-variety group also supports the conclusion that this group was employing a dual-performance strategy. The lack of differences in the high-variety group implies that this group employed a unitary strategy for computing answers to all items. In addition, there was some evidence that performance strategies were differentially influenced by concurrent-task skill, as shown by differences in old and new problems under the different test conditions. In both tasks, dual-task practice moderated the extent to which the subjects were able to employ a dual strategy. This influence was revealed in the complex interactions between the practice variables and test conditions in both tasks.

Inspection of the performances for each of the groups suggested that very little differential processing of items occurred after practicing with a high variety of items. For trigrams, significant interactions between the two practice variables were obtained at each of the joint levels of item and test mode (see Figures 13 and 15). For math, the four-way interaction was not significant but inspection of the item by test mode interactions for each group revealed a pattern very similar to the trigram results. After dual-task low-variety practice, substantial differences between types of items were found at all levels of test mode; after single-task, low-variety practice, differences between item types were observed only on single-task performance. On the other hand, high-variety groups under both practice mode conditions, and for both tasks, displayed equivalent patterns of performance in solving new and old items. This suggests the conclusion that both the operational skills and concurrent-task skills possessed by subjects will mediate the types of performance strategies employed in complex task performance.

Furthermore, the obtained patterns of interactions of the practice variables with the test conditions suggest that the subjects used the same strategies across the tasks. The overall degree of consistency between the two tasks in the obtained pattern of results, in spite of the differences in their specific performance requirements, implies that subjects bring a general style or *modus operandi* to complex task performance which is general across task components. This idea is not novel, either in the cognitive or performance literature. In problem-solving literature, the notions of set and functional fixity both imply that there are subject-bound strategies for performing tasks. The levels of processing concept (Craik & Lockhart, 1972) can be interpreted as the application of different experimènter-induced strategies to memory encoding. In the dual-task literature, Damos and Smist (1980, 1981) identified different response strategies (i.e., massed, alternating, and simultaneous) which characterized subjects' performances. The present study extends the notion of performance strategies in performance literature to memory-encoding processes. Moreover, to the author's knowledge the current results are unique in demonstrating that the variety provided during practice is an important variable in accounting for strategy differences and in its investigation of dual-task practice as a moderating variable. Thus, it suggests a general framework for understanding complex skill by describing the ways in which declarative and procedural skills are utilized in complex performance.

Retention Transfer Session

The second major objective of the present study was to investigate the role of memory decay in the maintenance of cognitive skills and strategies. Specifically, the retention transfer session was designed to test the relative degree of decay of declarative and procedural skills and the maintenance of the strategies associated with these skills. Memory decay was experimentally manipulated by testing five subjects from each of the practice groups at retention intervals of 1, 2, 3 and 5 days after the initial session. Analysis of the retention data followed a pattern similar to that employed in analyzing the immediate transfer session.

Retention for both procedural and declarative skills was predicted to be negatively related to the length of the retention interval. It was hypothesized that retention of the procedural skills would be superior to retention of declarative skills because of the specificity of the knowledge base for declarative skills. In addition to main effects for retention, the analyses focused on three more specific aspects of memory decay. These were (a) the extent to which operational skills decayed as a function of practice; (b) the decay of concurrent-task skills; and (c) the consequent maintenance of strategies after the delay.

Although no statistical analysis compared the immediate with the retention performance, inspection of the mean levels of performance revealed that after the delay, the solution times for both math and trigrams were superior to those obtained during the immediate transfer phase. This surprising result may have occurred because the immediate transfer scores were depressed due to fatigue. All of the subjects practiced the tasks for approximately one hour before the immediate transfer session, and although a 10-minute break occurred between the acquisition and transfer phases, fatigue could have affected the level of performance. It is also probable that the immediate transfer session as well as the trials in the retention transfer session provided inadvertant opportunity for learning to occur. Nevertheless, because retention interval was a between-groups variable, the analysis of the retention session data *per se* does provide evidence of the effects of retention on skill and strategy maintenance.

General effects of retention. With respect to the overall effects of retention, the analysis indicated that the main effect of retention was significant for trigrams on the CRI measure. Transfer performance was inversely related to the length of the retention interval with a decay of about 0.2 seconds per response per day. Across the five days, solution times decreased about 30%. In addition, retention interval and practice mode interacted. However, the pattern of results did not reveal any systematic differences in retention as a function of multiple-task practice conditions. On the math task, the effects of the retention interval were not significant, nor did it interact with any other variable.

Thus, with trigrams, decay was apparently general across groups and conditions. The specific types of items, test conditions and practice modes were unrelated to the retention interval. These results, and the total absence of significant effects in the math task, were surprising. As discussed earlier, one possible reason for these results may have been that the effects were confounded with learning, since the retention phase included about 16 minutes of performance for each task. It is also possible that the length of the retention interval was insufficient for decay to occur. Motor learning generally has been found to be resistent even to long periods of delay (see, for example, reviews by Irion, 1966, and Hedge, 1980). however, studies in which the test materials can be described as declarative such as lists of words, retention intervals of minutes are often sufficient to produce forgetting (Underwood, 1983). This suggests an alternative hypothesis-- that the critical interval for finding decay effects may have been missed.

The reasons for the lack of effects, therefore, remain somewhat a mystery, especially in regards to the decay of declarative skills. Future research could improve on this study by using different retention intervals, in order to identify end-points for decay effects, and by employing designs in which retention is not confounded with learning effects. For example, if practice groups similar to the ones in this study had been tested in a between-groups design on single- and dual-task performances, it would have been possible to investigate relearning curves, and thereby identify more precisely whether initial and more stable retention effects were present.

A final finding was the differences between tasks. The finding of an effect for trigrams but not for math may be a function of the differences in the task characteristics. The trigram task was composed of random 3-letter sequences and was generally nondistinctive. With the prolonged practice, subjects apparently found ways to learn the specific trigrams as indicated by the initial transfer session, but across time, these traces showed decay. With respect to math, our culture provides extensive practice memorizing number sequences and the math problems may have been perceived as distinctive and, therefore, may have been encoded more effectively. This interpretation is consistent with the cognitive literature related to retention. Tulving (1978) and others (Jacoby & Craik, 1978; Underwood, 1983) have suggested that distinctiveness of items is a more important factor in efficiency of memory encoding than mere repetition *per se*. However, this study did not investigate differences in task characteristics and so the interpretation is a tenuous one. Future research is needed to study the effects of task differences in concurrent-task performance on both acquisition and decay.

Variety of practice and skill maintenance. One specific focus of the retention analysis was to explore the extent to which procedural and declarative skills decayed during the retention transfer session. The analysis of the retention transfer data for math suggested that the variety of problems solved during practce did not differentially affect retention. New items continued to be solved faster than old ones. Furthermore, practice variety continued to interact with items, as in the immediate transfer. Between-groups comparisons indicated that prior learning of a small item set continued to result in faster RT on these problems while novel problems were solved at equivalent speeds. Within each group, old problems were solved more quickly than novel ones.

For trigrams, the variety of practice continued to be an important variable with respect to influencing solution times for the two types of items. Interesting differences from the immediate transfer emerged, however, which may be related to the decay of skills.

The locus of between-group differences was found in the new and not the repeated problems. In a relative sense, therefore, greater decay in both procedural and declarative skills seems to have occurred in the low-variety group. Although the repeated problems were solved faster directly after low-variety practice than after high-variety practice, the groups' performances following the retention interval were equivalent. This suggests that specific knowledge was not retained any better after extensive practice with the repeated items. Given the additional opportunities to learn in the retention interval, this conclusion is tenuous and would need to be demonstrated under more controlled conditions. With respect to new items the differences between variety groups suggests that procedural skills decayed relatively more after the low-variety practice, the two groups were equivalent during the immediate transfer. The implication is that lack of practicing procedural skills may lead to more overall forgetting.

Retention of concurrent-task skills. The analysis of the retention data also examined the relative retention of multiple-task skills. Only one prior study (Adams and Hufford, 1962) has apparently addressed this question but some authors (e.g., Battig, 1979) suggest that the interference during learning, such as the presence of a concurrent task, might actually result in better retention. Such interference could require a learner to engage in more elaboration of task materials, leading to stronger memory traces (Jacoby & Craik, 1978).

Results of the math analysis indicated that there was no main effect of test mode. Relative to immediate transfer, only small increases in time were found as a function of the number of tasks performed concurrently. In addition, processing load did not interact with practice mode.

In the trigram task, significant differences between single-task and the two multiple-task conditions continued to be found, but there was no evidence across levels of variety that the initial advantage of dual-task practice was maintained. There was, however, a complex interaction between the two practice variables and test mode. Analyses conducted between levels of practice mode revealed that within the high-variety group, single and dual-task performances were equivalent, but at the triple-task condition, the performance of the single-task practice group exceeded that of the dual-task group. Within the low-variety group, statistical differences did not emerge; however, inspection of the data suggests that the advantage of the dual-task practice group was maintained.

These results suggest two conclusions. First, both the math and the trigram results imply that prior dual-task practice did not by itself provide any longlasting advantage for multiple-task performance. Adams and Hufford's (1962) study offer some support for this finding in that their whole-task practice group exhibited only a transient advantage over their part-task group after delay.

Furthermore, the trigram results suggest that the demands caused by new items under high-variety and dual-task conditions during practice may have interfered with the effective retention of dual-task skills. Although the conclusion must be tentative, it appears that the greatest amount of retention for dual-task skill occurred when the dual-task practice did not include much variety. Thus, adding variety to the load already imposed by learning concurrent-task management skills may have resulted in decreased encoding of those skills. Differences between the high-variety groups trained under dual- and single-task conditions, which occurred in the triple-task performance, are consistent with this interpretation. In addition, there was a tendency for the performance of the low-variety dual-task group to exceed that of the high-variety dual-task group. Thus, although concurrent-task practice is apparently necessary to acquire concurrent-task skills, as has been observed by a number of prior researchers, learning these skills in the face of other requirements may produce an overload leading to poorer retention. On the other hand, learning component skills in an environment devoid of concurrent-task practice may produce learning which cannot be effectively applied in a complex transfer situation.

Maintenance of strategies during retention. Finally the analysis explored whether the strategies exhibited directly after practice continued to be utilized in the retention session. It was of particular interest to examine whether dual strategies would be found during this phase or whether subjects would revert to solving both old and new problems by calculating answers. No a priori hypotheses were made because there was no prior demonstration that dual-processing strategies would be utilized in the first place. However, if knowledge of old items were forgotten, it might be expected that subjects would revert to a unitary strategy of computing answers to all problems.

The pattern of interactions between variety and items were consistent with the conclusion that across practice and test mode, low-variety practice was condusive to maintaining a dual strategy. For math, this finding must be tempered by the fact that the single-task low-variety group did not display a dual strategy during the immediate transfer. Moreover, the pattern of results found for math suggests that subjects in the high-variety condition began to process repeated items by retrieval, implying that they had learned to recognize their occurence.

For trigrams, as in the first session, concurrent-task skills moderated the extent to which dual strategies were used; only after dual-task low-variety practice was any substantial difference observed between novel and repeated problems. These results were further supported by the results of the Chi-square tests. These tests indicated that after dual-task practice, the type of variety during practice was related to median difference score between old and new problems; these effects were observed at the dual- and triple-task levels. Similar tests for the single-task group were not significant. Thus, after a combination of dual-task and low-variety practice, subjects apparently retained the dual strategy of retrieving old items while computing the answers to new ones. On the other hand, subjects in the single-task low-variety group were apparently never able or willing to use declarative skills to a great extent in responding to the complexity of the transfer sessions..

Implications and Limitations

Although the research discussed here did not attempt to model the characteristics of any specific system, its results have strong implications for the expected performance of operaters of systems which require problem-solving skills under complex conditions. Given the basic nature of the investigation, the results cannot be directly applied to the design of an operation system; rather, its value is to suggest principles to be applied to the training of operators of complex systems and to the allocation of system demands.

One principle which is clearly indicated by the results is that operaters will utilize a variety of performance strategies in fulfilling the demands of complex tasks. Strategies are probably stable over time to the degree that they involve cognitive processes that are successful in task accomplishment. Moreover, the results of this study imply that the choice of strategy for performing tasks can be partly controlled through the mix of cognitive skills which can be brought to bear on the task. Although it was not investigated here, the results of Damos and Wickens (1980) suggest that operaters will bring preferred strategies to a task. In addition, past experience, individual differences in various cognitive skills, subjective preferences for the components of a complex task, and perceived utility of different tradeoffs among components all probably contribute to the adoption and utilization of a particular strategy by a particular individual. One area for further theoretical and applied research on strategies is the investigation of individual difference variables, in the encoding of procedural and declarative skills and the subsequent utilization of performance strategies.

Furthermore, different tasks undoubtably require different mixes of cognitive skills that can combined through strategies in more or less efficient ways. Task variables such as difficulty or pacing may constrain or otherwise influence the types of strategies which lead to effective performance. Through task analytic techniques which recognize compensatory requirements, optimal strategies for task performance can be identified, which account for differences among individuals.

However, the general processes suggested here--encoding procedural skills and/ or declarative skills--appear to be robust in terms of their application to complex problem-solving tasks which include both novel and repeated situations. The strategies involved in such environments would be conceptually similar to those described here. Therefore, in principle, if tasks call for a finite and somewhat repetitive universe of responses, training development and performance evaluation should consider the several types of activities to be performed. Given the results of this study and the dearth of prior research, the effects of task variety seems to be a prime area for study to further the theoretical understanding of cognitive processes.

A second principle suggested by this study is related to the effects of dual-task training on performance in the complex transfer sessions. Optimal transfer to a multiple-task environment, such as flying or driving, will occur when learning takes place under multiple-task conditions. Practice in component skills may be insufficient for effective performance under concurrent-task conditions. Reflection on the relative performances of the four groups during the immediate transfer session suggests that without prior dual-task training, the detrimental effects of increasing task load were high. In particular, performance after single-task practice with a low variety of problems was detrimentally affected, even for problems they had seen repeated for an hour. These results clearly suggest that learning to manage the joint demands of tasks is important if they are to be performed together. With respect to optimizing transfer, therefore, this study adds to the literature in indicating that training designs should incorporate the time-sharing requirements of the task.

Comparison of the groups during both transfer phases also suggests that training designs which incorporate planned sequences may be more successful than trying to simulate total fidelity. The group which practiced under conditions most closely representing the transfer phase never appeared to differentiate between old and new problems nor to reduce the effects of processing load. In contrast, the performance of the group trained under high-variety single-task conditions showed a dramatic reduction in processing load effects during the sessions as well as some evidence for a dual strategy in the second session. Furthermore, practice with a small number of items under dual-task conditions resulted in an apparent reduction in test mode effects for new problems, while yielding large differences between new and repeated items. Thus, for both conditions in which only one of the skills was trained, the evidence suggests that sequential learning effects occurred.

In conclusion, too many demands during either the practice or transfer may lead to non-optimal utilization of strategies. To be sure, the principles implied by this analysis and study are limited by the relative simplicity of the tasks, the nature of the transfer sessions, and the relative shortness of the retention interval. Nevertheless, the findings of strategy development and maintenance in complex problem-solving have strong implications for the optimal design of complex systems and the training of operators of such systems. Further investigations of the conditions and training sequences which lead to the development and maintenance of declarative and procedural skills, and of performance strategies, will ultimately improve our understanding of the components which contribute to effective performance.

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APPENDIX A

COMPUTER PROGRAM FOR RUNNING TASKS

```
10 CLEAR 2500
20 DIM NC(80),T$(4,48),ST9(2),CST9(2),R1$(2),T3(2)
30 DIM OLDT3(2),T7(2),T5(2),N1(2),C1(2),CT$(3),TS$(2)
40 DIM UO%(3),UGU(6),A$(6),CH$(15),A3$(3),N(6)
50 DIM AA$(4,5),KX(4),KY(4),AM(4,2)
60 DIM IN(7),N2(2,2),C2(2,2),N3(2,2),C3(2,2)
70 DIM ZO(4)
80 DEF FNR1(X)=INT(SQR(RND(1)*100))
90 UO%(0)=&H36: UO%(1)=&H1FF: UO%(2)=&H77D8: UO%(3)=&HC9
100 OPEN "I",#3,"INPUT.FLE"
110 PRINT CHR$(27); CHR$(69);
120 PRINT CHR$(27);CHR$(89);CHR$(32);CHR$(32);CHR$(27);CHR$(106)
130 REM LINE 100 SAVE CURSER POSITION OF LINE 1 COLUMN 1
140 REM READ IN NUMBER CONDITION TABLE
150 LINE INPUT #3,T1$
160 FOR J=1 TO 80
170    TEM$=MID$(T1$,J,1)
180 NC(J)=VAL(TEM$)
190 NEXT J
200 REM READ IN TASK ORDERING FOR I=1 TO 4
210 LINE INPUT #3,T2$
220 FOR J=1 TO 24
230 T$(1,J)=MID$(T2$,J,1): T$(2,J)=MID$(T2$,J,1)
240 NEXT J
250 LINE INPUT #3,T3$
260 FOR J=1 TO 48
270 T$(3,J)=MID$(T3$,J,1): T$(4,J)=MID$(T3$,J,1)
280 REM T$(I,J)=MID$(T2$,J+24,1)
290 NEXT J
300 LINE INPUT #3,QZ$
310 REM READ IN PRIORITIES FOR DUAL CHANGING
320 PRINT CHR$(27);CHR$(69);     :REM CLEARS SCREEN
330 PRINT "WHAT IS YOUR SUBJECT NUMBER "
340 INPUT SN
350 PRINT CHR$(27);CHR$(69);
360 FOR I=1 TO 80
370 LINE INPUT #3,WC$
380 LINE INPUT #3,WM$
390 IF I=SN GOTO 410
400 NEXT I
410 LY=1
420 FOR LZ=0 TO 4
430 FOR LX=0 TO 2
440 TT$=MID$(WM$,LY,2)
450 LY=LY+2
460 AM(LZ,LX)=VAL(TT$)
470 NEXT LX
480 NEXT LZ
490 KY=0
500 FOR KZ=0 TO 4
510 FOR KX=0 TO 5
520 KY=KY+1
530 AA$(KZ,KX)=MID$(WC$,KY,1)
540 NEXT KX: NEXT KZ
550 CLOSE 3
560 RESET "SY0:"
570 PRINT CHR$(27);CHR$(69)
580 PRINT CHR$(27);CHR$(89);CHR$(40);CHR$(32);"    "
590 OPEN "O",#2,"SY0:TRAIN.OPT"
600 PRINT CHR$(27);CHR$(69);     :REM CLEARS SCREEN
```

```
610 REM ******************** CODE FOR TRAINING PHASE *********************
620 DUAL$="OFF"
630 CRI$="NO"
640 T1$=" ":T2$=" "
650 CC=NC(SN)
660 IF CC=1 OR CC=2 THEN GOTO 760
670 PRINT "THIS IS PROJECT ENCODE. DURING THIS PHASE OF THE STUDY YOU WILL BE@
PROVIDED WITH PRACTICE ON THE MENTAL ARITHMETIC AND COTRAN TASKS."
680 PRINT "THE TWO TASKS WILL BE PRESENTED TO YOU AT THE SAME TIME FOR 24@
TRIALS. EACH TRIAL WILL LAST FOR TWO MINUTES AND AFTER EACH TRIAL YOU"
690 PRINT "WILL BE SHOWN A SUMMARY OF YOUR PERFORMANCE ON EACH TASK. AFTER EACH@
FOUR TRIALS YOU WILL BE GIVEN A ONE MINUTE REST."
700 PRINT "     FOR EACH PROBLEM, RESPOND AS QUICKLY AS POSSIBLE WHILE TRYING@
TO MAINTAIN A HIGH LEVEL OF ACCURACY. LEARN TO COORDINATE BETWEEN TASKS"
710 PRINT "SO THAT YOU MAINTAIN THE BEST PERFORMANCE YOU CAN ON BOTH TASKS.@
ON SUCCESSIVE TRIALS TRY TO OBTAIN A SMALLER CORRECT RESPONSE TIME (CORRECT"
720 PRINT "R.T.) THAN ON THE PRECEDING TRIAL WHILE MAINTAINING 95% ACCURACY."
730 REM DUAL$="ON"
740 OPEN "O",#1,"SYO:TRAIN.LOG"
750 GOTO 810
760 PRINT "THIS IS PROJECT ENCODE. DURING THIS PHASE OF THE STUDY YOU WILL@
BE PROVIDED WITH PRACTICE ON THE MENTAL ARITHMETIC AND COTRAN TASKS."
770 PRINT "EACH OF THE TASKS WILL BE PRESENTED TO YOU FOR 12 TRIALS. EACH TRIAL@
WILL LAST FOR TWO MINUTES AND AFTER EACH TRIAL YOU WILL BE SHOWN A @
SUMMARY OF YOUR PERFORMANCE FOR THE TASK."
780 PRINT "AFTER EACH FOUR TRIALS YOU WILL BE GIVEN A ONE MINUTE REST."
790 PRINT "     FOR EACH PROBLEM, RESPOND AS QUICKLY AS POSSIBLE WHILE @
MAINTAINING A HIGH LEVEL OF ACCURACY.  THAT IS, ON SUCCESSIVE TRIALS, TRY"
800 PRINT "TO OBTAIN A SMALLER CORRECT RESPONSE TIME (CORRECT R.T.) THAN ON@
THE PRECEDING TRIAL WHILE MAINTAINING 95% ACCURACY."
810 PRINT "LEARNING EACH OF THE TASKS IS EQUALLY IMPORTANT, SO PLEASE DO NOT@
FAVOR ONE TASK OVER ANOTHER BECAUSE YOU THINK IT IS MORE INTERESTING,"
820 PRINT "OR DIFFICULT, OR FOR ANY OTHER REASON. AT FIRST YOU WILL PROBABLY@
HAVE TO 'WORK OUT' THE ANSWERS TO THE PROBLEMS, BUT AFTER SOME "
830 PRINT "PRACTICE, YOU MAY HAVE LEARNED THE CORRECT ANSWERS TO SOME OR ALL@
OF THE PROBLEMS."
840 PRINT " "
850 PRINT "REMEMBER: LEARN TO PERFORM BOTH TASKS AS WELL AS POSSIBLE DURING@
THIS ONE HOUR PRACTICE SESSION."
860 PRINT "PRESS THE RETURN KEY WHEN YOU ARE READY TO BEGIN."
870 FOR I=1 TO SN: R=RND(1): NEXT I
880 INPUT KK$
890 PRINT CHR$(27);CHR$(69);
900 IK=1: ZZ=0
910 FOR KK=1 TO 6
920 PRINT CHR$(7);:PRINT CHR$(7);
930 PRINT CHR$(27);CHR$(89);CHR$(40);CHR$(45);
940 PRINT"*********************** BLOCK ";KK;" ***************************"
950 POKE 8220,0: POKE 8219,0
960 W1=PEEK(8220)
970 IF W1<5 THEN GOTO 960
980 PRINT CHR$(27);CHR$(69);
990 FOR JJ=1 TO 4
1000 FOR I=0 TO 4: ZO(I)=0: OGO(I)=RND(1): NEXT I
1010 FOR I=0 TO 4: FOR J=0 TO 4
1020 IF OGO(J)-OGO(I)<=0 THEN GOTO 1030 ELSE GOTO 1040
1030 ZO(J)=ZO(J)+1
1040 NEXT J: NEXT I
1050 ZZ=ZZ+1: FC=0: FM=0
1060 IF CC=1 OR CC=2 THEN GOTO 1200
```

```
1070 REM **************DUAL-TASK TRAINING*******************
1080 DUAL$="ON"
1090 KN=6
1100 MSEC$="N": CSEC$="N": VSEC$="N": TUP$="N"
1110 MFIRST$="Y": CFIRST$="Y": VFIRST$="Y"
1120 FOR I=1 TO 5
1130 DEF USR0=VARPTR(U0%(0)): KZ=USR0(0)
1140 NEXT I
1150 T1$=T$(CC,IK):  T2$=T$(CC,IK+1)
1160 IK=IK+2
1170 GOSUB 5590:     REM SUBROUTINE FOR DUAL TASK PRESENTATION
1180 GOTO 1280
1190 REM SINGLE TASK TRAINING, CONDITION 1 TO 2
1200 FOR I=1 TO 5
1210 DEF USR0=VARPTR(U0%(0)): KZ=USR0(0)
1220 NEXT I
1230 T1$=T$(CC,IK)
1240 REM CALL TO SUBROUTINE TO PRESENT TASK
1250 IF T1$="M" THEN KN=1 ELSE IF T1$="C" THEN KN=2
1260 IF T1$="M" THEN GOSUB 2660 ELSE IF T1$="C" THEN GOSUB 3610
1270 IK=IK+1
1280 NEXT JJ
1290 PRINT CHR$(27);CHR$(69)
1300 POKE 8220,0: POKE 8219,0
1310 PRINT CHR$(27);CHR$(89);CHR$(40);CHR$(45);
1320 PRINT "****************** END OF BLOCK ";KK;" *******************"
1330 IF KK=6 THEN GOTO 1420
1340 PRINT CHR$(27);CHR$(89);CHR$(45);CHR$(45);
1350 PRINT "****************** TAKE A ONE MINUTE BREAK *****************"
1360 POKE 8220,0: POKE 8219,0
1370 W1=PEEK(8220)
1380 IF W1<120 THEN GOTO 1370
1390 PRINT CHR$(27);CHR$(69);
1400 NEXT KK
1410 REM 10 MINUTE BREAK REPLACE DISKETTE FOR CRITERION PHASE
1420 CLOSE
1430 PRINT CHR$(27);CHR$(89);CHR$(40);CHR$(32);"    "
1440 PRINT "THIS IS THE END OF THE TRAINING PHASE OF PROJECT ENCODE. YOU WILL a
NOW HAVE A 10 MINUTE BREAK BEFORE THE NEXT PHASE. PLEASE TELL THE EXPERIMENTER."
1450 INPUT KK$: IF KK$<>"G" THEN GOTO 1450
1460 RESET "SY0:"
1470 PRINT CHR$(27);CHR$(69)
1480 REM ******************CODE FOR CRITERION PHASE******************
1490 PRINT CHR$(27);CHR$(89);CHR$(40);CHR$(32);"  "
1500 PRINT "THE NEXT PHASE OF THE STUDY IS THE CRITERION PHASE.  DURING THIS"
1510 PRINT "PHASE YOU WILL BE TESTED ON THE MENTAL ARITHMETIC, COTRAN, AND THE"
1520 PRINT "DELAYED REACTION TIME TASKS. THE TASKS WILL BE PRESENTED BOTH ALONE"
1530 PRINT "AND IN COMBINATION DURING THIS PHASE. TRY TO PERFORM ALL OF THE TASKS"
1540 PRINT "PRESENTED AS QUICKLY AS POSSIBLE WHILE MAINTAINING 95% ACCURACY."
1550 PRINT "CONSIDER THE TASKS AS EQUALLY IMPORTANT AND DO NOT FAVOR ONE OVERa
ANOTHER DURING THIS PHASE.  THAT IS, TRY TO MAINTAIN A BALANCE IN THE LEVEL OFa
PERFORMANCE FOR ALL TASKS PRESENTED TOGETHER."
1560 PRINT "   PRESS THE RETURN KEY WHEN YOU ARE READY TO BEGIN."
1570 LY$="1112223"
1580 TY$="M  C  V  VM VC MC VMC"
1590 CRI$="YES"
1600 CC=5
1610 OPEN "O",#1,"SY0:CRI1.LOG"
1620 OPEN "O",#2,"SY0:CRI1.OPT"
1630 IN(7)=7
```

```
1640 FOR I=1 TO 6
1650 IN(I)=0
1660 OGD(I)=RND(1)
1670 NEXT I
1680 FOR I=1 TO 6
1690 FOR J=1 TO 6
1700 IF OGD(J)-OGD(I)<=0 THEN GOTO 1710 ELSE GOTO 1720
1710 IN(J)=IN(J)+1
1720 NEXT J
1730 NEXT I
1740 INPUT KK$: PRINT CHR$(27);CHR$(69)
1750 FOR IQ=1 TO 7
1760 KN=IN(IQ)
1770 FOR I=0 TO 4: ZO(I)=0: OGD(I)=RND(1): NEXT I
1780 FOR I=0 TO 4: FOR J=0 TO 4
1790 IF OGD(J)-OGD(I)<=0 THEN GOTO 1800 ELSE GOTO 1810
1800 ZO(J)=ZO(J)+1
1810 NEXT J: NEXT I
1820 MSEC$="N": CSEC$="N": VSEC$="N": TUP$="N"
1830 MFIRST$="Y": CFIRST$="Y": VFIRST$="Y" :CZ=0:MZ=0:FC=1:FM=0
1840 FOR IZ=1 TO 5
1850 DEF USR0=VARPTR(UO%(0)): KZ=USR0(0)
1860 NEXT IZ
1870 CZ=IN(IQ)*3-2
1880 TEM$=MID$(LY$,IN(IQ),1): REM SINGLE=1 DUAL=2 TRIPLE=3
1890 TT=VAL(TEM$)
1900 FOR J=1 TO 3        :REM SET UP TASKS 1-3 FOR CRITERION PHASE
1910 CT$(J)=MID$(TY$,CZ,1)
1920 CZ=CZ+1
1930 NEXT J
1940 ZZ=ZZ+1
1950 DUAL$="OFF"
1960 ON TT GOTO 1970,2000,2040:   REM CALL FOR SINGLE,DUAL,TRIPLE COMBINATION
1970 REM BEGINNING OF CODE FOR SINGLE TASKS
1980 IF CT$(1)="M" THEN GOSUB 2660 ELSE∂
       IF CT$(1)="C" THEN GOSUB 3610 ELSE GOSUB 4790
1990  GOTO 2500
2000 REM BEGINNING CODE FOR DUAL TASKS
2010 T1$=CT$(1): T2$=CT$(2): DUAL$="ON"
2020 GOSUB 5590          :REM PRESENTS DUAL TASKS
2030 GOTO 2500           :REM END OF CODE FOR DUAL TASKS
2040 REM BEGINNING OF CODE FOR TRIPLE TASKS
2050 PRINT CHR$(27);CHR$(69)
2060 DUAL$="ON"
2070 S2=4: T4=0: FIRST$="Y"
2080 POKE 8220,0: POKE 8219,0
2090 GOSUB 2660: MFIRST$="N"
2100 GOSUB 3610: CFIRST$="N"
2110 GOSUB 4790: VFIRST$="N"
2120 DEF USR0=VARPTR(UO%(0)): K%=USR0(0)
2130 S1$=CHR$(K%)
2140 LOW=PEEK(8219): HIGH=PEEK(8220)
2150 T8=LOW/500+HIGH/2
2160 IF T8>120 THEN GOTO 2310
2170 IF S1$="J" OR S1$="K" THEN II=0 ELSE ∂
        IF S1$="D" OR S1$="F" THEN II=1 ELSE ∂
          IF S1$="U" OR S1$="W" OR S1$="O" OR S1$="P" THEN II=2 ELSE  ∂
            GOTO 2120
2180 TO=T7(II)
2190 IF FIRST$="Y" THEN GOTO 2210
```

```
2200 IF S2<>II THEN T7(II)=T4
2210 T9=T8-T7(II)
2220 T0=T8-T0
2230 FIRST$="N"
2240 IF T9>=0 THEN GOTO 2280
2250 IF HIGH <> T5(II) THEN GOTO 2310
2260 T7(II)=T7(II)-.5: T9=T8=T7(II)
2270 T0=T0+.5
2280 IF S1$="J" OR S1$="K" THEN GOSUB 2660 ELSE IF S1$="D" OR S1$="F" a
        THEN GOSUB 3610 ELSE GOSUB 4790
2290 IF TUP$="Y" THEN GOTO 2310
2300 GOTO 2120
2310 TS$(0)=" M ": TS$(1)=" C ": TS$(2)= " V "
2320 FOR R=0 TO 2
2330 RR=R+1
2340 IF N1(R)<>0 THEN ART=ST9(R)/N1(R) ELSE ART=0
2350 IF C1(R)<>0 THEN ACRT=ST9(R)/C1(R) ELSE ACRT=0
2360 IF R<>2 GOTO 2400
2370 PRINT #2;USING "###";SN;ZZ;NC(SN);KN;RR;N1(R);C1(R);
2380 PRINT #2,USING "####.##";ART;ACRT
2390 GOTO 2460
2400 FOR JR=1 TO 2
2410 IF C2(JR,RR)<>0 THEN C3(JR,RR)=N3(JR,RR)/C2(JR,RR) ELSE C3(JR,RR)=0
2420 IF N2(JR,RR)<>0 THEN N3(JR,RR)=N3(JR,RR)/N2(JR,RR) ELSE N3(JR,RR)=0
2430 NEXT JR
2440 PRINT #2,USING "###";SN;ZZ;NC(SN);KN;RR;N1(R);C1(R);
2450 PRINT #2,USING "####.##";ART;ACRT;N2(1,RR);C2(1,RR);N3(1,RR);C3(1,RR);
     N2(2,RR);C2(2,RR);N3(2,RR);C3(2,RR)

2460 IF C1(R)<>0 THEN C1(R)=(C1(R)/N1(R))*100 ELSE C1(R)=0
2470 CST9(R)=ACRT
2480 NEXT R
2490 PRINT CHR$(27);CHR$(69)
2500 NEXT IQ
2510 PRINT CHR$(27);CHR$(89);CHR$(40);CHR$(32);" "
2520 PRINT "TASK","# RESP","% CORRECT","CORRECT R.T."
2530 PRINT "----","------","---------","------------"
2540 PRINT "MATH",N1(0),C1(0),CST9(0)
2550 PRINT "COTRAN",N1(1),C1(1),CST9(1)
2560 PRINT "DELAYED R.T.",N1(2),C1(2),CST9(2)
2570 POKE 8220,0: POKE 8219,0
2580 W1=PEEK(8220)
2590 IF W1<20 THEN GOTO 2580
2600 CLOSE
2610 PRINT CHR$(27);CHR$(69)
2620 PRINT CHR$(27);CHR$(89);CHR$(40);CHR$(32);"  "
2630 PRINT "THIS CONCLUDES THIS SESSION OF PROJECT ENCODE. PLEASE LET THE"
2640 PRINT "EXPERIMENTER KNOW THAT YOU HAVE FINISHED. THANK YOU."
2650 END
2660 REM************************** MATH SUBROUTINE **************************
2670 IF DUAL$="OFF" THEN GOTO 2700
2680 IF MSEC$ ="Y" GOTO 3240
2690 IF MFIRST$<> "Y" THEN GOTO 2780
2700 T9=0: T8=0: T7(0)=0: N1(0)=0: C1(0)=0: B1=0: A1=0: ST9(0)=0
2710 CST9(0)=0: K1$(0)=" ": R2=0: S1$=" ": FM=0
2720 T3(0)=0: OLDT3(0)=0: T5(0)=0: T0=0
2730 FOR I=1 TO 2
2740 N2(I,1)=0: N3(I,1)=0: C2(I,1)=0: C3(I,1)=0:
2750 NEXT I
2760 IF DUAL$="ON" THEN GOTO 2780
2770 POKE 8220,0: POKE 8219,0
2780 OLDT3(0)=T3(0):  T3(0)=PEEK(8220)
```

```
2790 IF T3(0)<240 AND T3(0)>=OLDT3(0) THEN GOTO 2820
2800 IF DUAL$="OFF" THEN GOTO 3410      :REM 2 MIN TIME LIMIT UP FOR SINGAL TASKS
2810 TUP$="Y": RETURN           :REM 2 MIN. TIME LIMIT UP FOR DUAL TASKS
2820 REM IF DUAL$="ON" THEN GOTO 2580
2830 REM CODE USED TO GENERATE MATH DIGITS X, Y, Z IF SUBJECT IS FIXED GROUP
2840 IF CC=1 OR CC=3 THEN ZM=FM ELSE ZM=ZO(FM)-1
2850 X=AM(ZM,0): Y=AM(ZM,1): Z=AM(ZM,2)
2860 FM=FM+1: IF FM>4 THEN FM=0
2870 MP=1
2880 IF CC=1 OR CC=3 THEN GOTO 3040
2890 REM CODE USED TO GENERATE MATH DIGITS X, Y, Z IF SUBJECT IS CHANGING GROUP
2900 RQ=RND(X)
2910 IF CRI$="YES" AND RQ<=.5 THEN GOTO 3040
2920 IF RQ<.34 THEN GOTO 3040
2930 MP=2
2940 RQ=RND(1)
2950 X=INT(RND(1)*100)+11: IF X>99 THEN GOTO 2940
2960 Y=INT(RND(1)*100)+11
2970 IF X=Y THEN Y=Y+FNR1(RQ)
2980 Z=INT(RND(1)*100)+11
2990 IF Z=X THEN Z=Z+FNR1(X)
3000 IF Z>99 THEN GOTO 2980
3010 IF Y>99 THEN GOTO 2960
3020 IF Z=Y THEN Z=Z+FNR1(X)
3030 IF Z>99 THEN GOTO 2980
3040 B1=RND(1):  A1=X+Y-Z
3050 R1$(0)="K":   REM DISPLAY INCORRECT ANSWER UNLESS B1>.5
3060 IF B1<.25 THEN A1=A1+1 ELSE IF B1<.5 THEN A1=A1+10 ELSE R1$(0)="J"
3070 T6=PEEK(8219): T5(0)=PEEK(8220)
3080 T7(0)=T5(0)/2 + T6/500
3090 IF T7<120 THEN GOTO 3120
3100 IF DUAL$="OFF" THEN GOTO 3410      :REM SINGLE TASK COMPLETED
3110 TUP$="Y": RETURN
3120 PRINT CHR$(27);CHR$(89);CHR$(45);CHR$(76);X;"!";Y;"?";Z;"=";A1;"  ";
3130 PRINT CHR$(27);CHR$(107)
3140 IF DUAL$="OFF" THEN GOTO 3160
3150 MSEC$="Y": RETURN
3160 DEF USR0=VARPTR(U0%(0)) :K%=USR0(0)
3170 T2=PEEK(8219): T1=PEEK(8220)        :REM CHECK TIME IN CASE RESPONSE MADE
3180 T8=T1/2 + T2/500: T9=T8-T7(0)                  :REM RESPONSE TIME COMPUTED
3190 IF T9>=0 THEN GOTO 3220
3200 IF T1<>T5(0) THEN GOTO 3410
3210 T7(0)=T7(0)-.5: T9=T8-T7(0)
3220 IF T8>120 THEN GOTO 3410
3230 IF K%=74 OR K%=75 GOTO 3240 ELSE GOTO 3160
3240 N1(0)=N1(0)+1: R2=0: ST9(0)=ST9(0)+T9:  REM # OF PROBLEMS ATTEMPTED
3250 N2(MP,1)=N2(MP,1)+1: N3(MP,1)=N3(MP,1)+T9
3260 IF DUAL$="OFF" THEN S1$=CHR$(K%)
3270 IF S1$<>R1$(0) THEN GOTO 3320
3280 PRINT
3290 PRINT CHR$(27);CHR$(89);CHR$(45);CHR$(95);"*";
3300 C2(MP,1)=C2(MP,1)+1
3310 C1(0)=C1(0)+1: R2=1: CST9(0)=CST9(0)+T9:  REM # OF PROBLEMS CORRECT
3320 FOR KJ=1 TO 20:NEXT KJ
3330 PRINT CHR$(27);CHR$(75);CHR$(27);CHR$(107);
3340 REM THE ABOVE LINE USES ESC K TO ERASE TO END OF LINE
3350 IF CC=1 OR CC=2 THEN GOTO 2780
3360 REM IF TT=1 THEN GOTO 2390
3370 PRINT #1,USING "###";SN;ZZ;NC(SN);KN;1;MP;R2;
3380 PRINT #1,USING "####.###";T9;T8;T0
```

```
3390 S2=0: T4=T8
3400 GOTO 2780
3410 IF N1(0)<>0 THEN ART=ST9(0)/N1(0) ELSE ART=0
3420 IF C1(0)<>0 THEN ACRT=ST9(0)/C1(0) ELSE ACRT=0
3430 FOR I=1 TO 2
3440 IF C2(I,1)<>0 THEN C3(I,1)=N3(I,1)/C2(I,1) ELSE C3(I,1)=0
3450 IF N2(I,1)<>0 THEN N3(I,1)=N3(I,1)/N2(I,1) ELSE N3(I,1)=0
3460 NEXT I
3470 PRINT CHR$(27);CHR$(69);
3480 PRINT #2,USING "###";SN;ZZ;NC(SN);KN;1;N1(0);C1(0);
3490 PRINT #2,USING "####.##";ART;ACRT;N2(1,1);C2(1,1);N3(1,1);C3(1,1);N2(2,1);
     C2(2,1);N3(2,1);C3(2,1)
3500 PRINT CHR$(27);CHR$(89);CHR$(40);CHR$(32);" "
3510 REM IF CRI$="YES" THEN GOTO 3066
3520 IF C1(0)<>0 THEN C1(0)=(C1(0)/N1(0))*100
3530 PRINT "TASK","# RESP","% CORRECT","CORRECT R.T."
3540 PRINT "----";"------";"---------";"-----------"
3550 PRINT "MATH",N1(0),C1(0),ACRT
3560 POKE 8220,0: POKE 8210,0
3570 W1=PEEK(8220)
3580 IF W1<15 GOTO 3570
3590 PRINT CHR$(27);CHR$(69);
3600 RETURN
3610 REM******************* COTRAN SUBROUTINE ******************************
3620 IF DUAL$="OFF" THEN GOTO 3650
3630 IF CSEC$="Y" GOTO 4440
3640 IF CFIRST$ <> "Y" THEN GOTO 3750
3650 NM$="XAZHQKIORAJETLS"
3660 T9=0:T8=0: N1(1)=0: T3(1)=0: OLDT3(1)=0: T7(1)=0: ST9(1)=0: CST9(1)=0
3670 R1$(1)=" ": R2=0: S1$=" ": C1(1)=0: T3(1)=0: OLDT3(1)=0: T5(1)=0
3680 FC=0: TO=0
3690 FOR I=1 TO 2
3700 N2(I,2)=0: N3(I,2)=0: C2(I,2)=0: C3(I,2)=0
3710 NEXT I
3720 IF DUAL$="ON" THEN GOTO 3750
3730 POKE 8220,0: POKE 8219,0
3740 REM **********************************
3750 OLDT3(1)=T3(1): T3(1)=PEEK(8220)
3760 IF T3(1) < 240 AND T3(1) >= OLDT3(1) THEN GOTO 3800
3770 IF DUAL$="OFF" THEN GOTO 4590
3780 TUP$="Y": RETURN
3790 REM CODE USED TO GENERATE LETTERS FOR COTRAN TASK IN FIXED GROUP
3800 REM *********************************
3810 IF CC=1 OR CC=3 THEN ZC=FC ELSE ZC=ZO(FC)-1
3820 FOR KZ=0 TO 5
3830 A$(KZ+1)=AA$(ZC,KZ)
3840 NEXT KZ
3850 FC=FC+1
3860 IF FC>4 THEN FC=0
3870 CP=1
3880 IF CC=1 OR CC=3 THEN GOTO 4110
3890 REM **************** ROUTINE FOR RANDOM PROBLEMS *****************
3900 RR=RND(1)
3910 IF CRI$="YES" AND RR<=.5 THEN GOTO 4110
3920 IF RR<.34 THEN GOTO 4110
3930 CP=2
3940 FOR I=1 TO 3
3950 N(I)=INT(RND(1)*13)+1
3960 IF N(I)<1 OR N(I)>13 THEN GOTO 3950
3970 IF I=1 THEN GOTO 4010
3980 FOR J=1 TO I-1
```

```
3990 IF N(I)=N(J) THEN N(I)=N(I)+1
4000 NEXT J
4010 FOR J=1 TO 3
4020 IF A$(J+3)<>A$(I) THEN GOTO 4050
4030 A$(J+3)=MID$(NM$,N(I),1)
4040 GOTO 4060
4050 NEXT J
4060 NEXT I
4070 FOR I=1 TO 3
4080 A$(I)=MID$(NM$,N(I),1)
4090 NEXT I
4100 REM **************DETERMINATION OF COTRAN ANSWER
4110 FOR I=1 TO 3
4120 FOR J=1 TO 3
4130 IF A$(J+3)<>A$(I) THEN GOTO 4160
4140 A3$(J)=A$(I+3)
4150 GOTO 4170
4160 NEXT J
4170 NEXT I
4180 REM ********************************
4190 R1$(1)="D"
4200 R=RND(1)
4210 IF R>.5 GOTO 4270
4220 K=FNR1(X): IF K>5 THEN GOTO 4250
4230 T$=A3$(2): A3$(2)=A3$(3): A3$(3)=T$
4240 GOTO 4260
4250 T$=A3$(1): A3$(1)=A3$(2): A3$(2)=T$
4260 R1$(1)="F"
4270 T6=PEEK(8219): T5(1)=PEEK(8220)
4280 T7(1)=T5(1)/2+T6/500
4290 IF T7(1)<120 THEN GOTO 4320
4300 IF DUAL$="OFF" THEN GOTO 4590
4310 TUP$="Y": RETURN
4320 PRINT CHR$(27);CHR$(89);CHR$(45);CHR$(45);A$(1);A$(2);A$(3);"  ";a
     A$(4);A$(5);A$(6);" = ";A3$(1);A3$(2);A3$(3);"    ";
4330 PRINT CHR$(27);CHR$(107)
4340 IF DUAL$="OFF" THEN GOTO 4360
4350 CSEC$="Y": RETURN
4360 DEF USR0=VARPTR(U0%(0)): K%=USR0(0)
4370 T2=PEEK(8219): T1=PEEK(8220)
4380 T8=T1/2+T2/500: T9=T8-T7(1)
4390 IF T9>=0 THEN GOTO 4420
4400 IF T1<>T5(1) THEN GOTO 4590
4410 T7(1)=T7(1)-.5: T9=T8-T7(1)
4420 IF T8>120 THEN GOTO 4590
4430 IF K%=68 OR K%=70 THEN GOTO 4440 ELSE GOTO 4360
4440 N1(1)=N1(1)+1: R2=0: ST9(1)=ST9(1)+T9: REM  # OF PROBLEMS ATTEMPTED
4450 N2(CP,2)=N2(CP,2)+1: N3(CP,2)=N3(CP,2)+T9
4460 IF DUAL$="OFF" THEN S1$=CHR$(K%)
4470 IF S1$<>R1$(1) THEN GOTO 4520
4480 PRINT CHR$(27);CHR$(89);CHR$(45);CHR$(60);"*";
4490 PRINT CHR$(27);CHR$(107)
4500 C1(1)=C1(1)+1: R2=1: CST9(1)=CST9(1)+T9: REM # OF PROBLEMS CORRECT
4510 C2(CP,2)=C2(CP,2)+1
4520 FOR KJ=1 TO 5: NEXT KJ
4530 IF CC=1 OR CC=2 THEN GOTO 3750
4540 REM IF IT=1 THEN GOTO 4090
4550 PRINT #1,USING "###";SN;ZZ;NC(SN);KN;Z;CP;R2;
4560 PRINT #1,USING "####.###";T9;T8;T0
4570 S2=1: T4=T8
```

```
4580 GOTO 3750
4590 IF N1(1)<>0 THEN ART=ST9(1)/N1(1) ELSE ART=0
4600 FOR I=1 TO 2
4610 IF C2(I,2)<>0 THEN C3(I,2)=N3(I,2)/C2(I,2) ELSE C3(I,2)=0
4620 IF N2(I,2)<>0 THEN N3(I,2)=N3(I,2)/N2(I,2) ELSE N3(I,2)=0
4630 NEXT I
4640 IF C1(1)<>0 THEN ACRT=ST9(1)/C1(1) ELSE ACRT=0
4650 PRINT CHR$(27);CHR$(69);
4660 PRINT #2,USING "###";SN;ZZ;NC(SN);KN;2;N1(1);C1(1);
4670 PRINT #2,USING "####.##";ART;ACRT;N2(1,2);C2(1,2);N3(I,2);C3(I,2);
     N2(2,2);C2(2,2);N3(2,2);C3(2,2)
4680 REM IF CRI$="YES" THEN GOTO 4216
4690 IF N1(1)<>0 THEN C1(1)=(C1(1)/N1(1))*100
4700 PRINT CHR$(27);CHR$(89);CHR$(40);CHR$(32);" "
4710 PRINT "TASK","# RESP","% CORRECT","CORRECT R.T."
4720 PRINT "----","------","---------","------------"
4730 PRINT "COTRAN",N1(1),C1(1),ACRT
4740 POKE 8220,0: POKE 8219,0
4750 W1=PEEK(8220)
4760 IF W1<15 THEN GOTO 4750
4770 PRINT CHR$(27);CHR$(69)
4780 RETURN
4790 REM ********************* VIGILANCE SUBROUTINE *********************
4800 IF DUAL$="OFF" THEN GOTO 4830
4810 IF VSEC$="Y" THEN GOTO 5280
4820 IF VFIRST$<> "Y" THEN GOTO 4900
4830 N1(2)=0: C1(2)=0: CST9(2)=0: ST9(2)=0: R1$(2)=" ": R2=0: S1$=" "
4840 T1=0: T2=0: T3(2)=0: OLDT3(2)=0: T5(2)=0: T7(2)=0: T8=0: T9=0
4850 T0=0
4860 IF DUAL$="ON" THEN GOTO 4880
4870 POKE 8220,0: POKE 8219,0
4880 R1$(2)="O"
4890 GOTO 4940
4900 OLDT3(2)=T3(2):  T3(2)=PEEK(8220)
4910 IF T3(2) <240 AND T3(2)>=OLDT3(2) THEN GOTO 4940
4920 IF DUAL$="OFF" THEN GOTO 5430
4930 TUP$="Y": RETURN
4940 RS=RND(1)
4950 LAN$=R1$(2)
4960 IF RS>.5 THEN GOTO 5050
4970 LT$="N"
4980 IF LAN$="W" THEN GOTO 5020 ELSE IF LAN$="O" THEN GOTO 5000
4990 IF RS<=.25 THEN GOTO 5020
5000 A1$="E": R1$(2)="W"
5010 GOTO 5030
5020 A1$="S": R1$(2)="O"
5030 PRINT CHR$(27);CHR$(89);CHR$(39);CHR$(34);A1$;
5040 GOTO 5120
5050 LT$="Y"
5060 IF LAN$="P" THEN GOTO 5100 ELSE IF LAN$="O" THEN GOTO 5080
5070 IF RS>.75 THEN GOTO 5100
5080 A1$="E": R1$(2)="P"
5090 GOTO 5110
5100 A1$="S": R1$(2)="O"
5110 PRINT CHR$(27);CHR$(89);CHR$(39);CHR$(100);A1$;
5120 T6=PEEK(8219): T5(2)=PEEK(8220)
5130 T7(2)=T5(2)/2+T6/500:   REM SIGNAL PRESENTED
5140 IF T7(2)<120 THEN GOTO 5170
5150 IF DUAL$="OFF" THEN GOTO 5430
5160 TUP$="Y": RETURN
5170 PRINT CHR$(27);CHR$(107): IF DUAL$="OFF" THEN GOTO 5190
```

```
5180 VSEC$="Y": RETURN
5190 DEF USR0=VARPTR(U0%(0))
5200 K%=USR0(0)
5210 T2=PEEK(8219): T1=PEEK(8220)        :REM CHECK TIME IN CASE A RESPONSE MADE.
5220 T8=T1/2 + T2/500: T9=T8-T7(2)
5230 IF T9>=0 THEN GOTO 5260
5240 IF T1<>T5(2) THEN GOTO 5430
5250 T7(2)=T7(2)-.5: T9=T8-T7(2)
5260 IF T8>120 THEN GOTO 5430
5270 IF K%=79 OR K%=80 OR K%=81 OR K%=87 THEN GOTO 5280 ELSE GOTO 5190
5280 N1(2)=N1(2)+1: R2=0: ST9(2)=ST9(2)+T9: REM  # OF PROBLEMS ATTEMPTED
5290 IF DUAL$="OFF" THEN S1$=CHR$(K%)
5300 IF S1$<>LAN$ THEN GOTO 5320
5310 C1(2)=C1(2)+1: R2=1: CST9(2)=CST9(2)+T9
5320 IF CC=1 OR CC=3 THEN GOTO 5360
5330 IF TT=1 THEN GOTO 5360
5340 PRINT #1,USING "###";SN;ZZ;NC(SN);KN;3;0;R2;
5350 PRINT #1,USING "####.###";T9;T8;T0
5360 S2=2: T4=T8
5370 IF LT$="N" THEN GOTO 5400
5380 PRINT CHR$(27);CHR$(89);CHR$(39);CHR$(100);CHR$(27);CHR$(75);
5390 GOTO 5410
5400 PRINT CHR$(27);CHR$(89);CHR$(39);CHR$(34);CHR$(27);CHR$(111);
5410 PRINT CHR$(27);CHR$(107)
5420 GOTO 4900
5430 IF N1(2)<>0 THEN ART=ST9(2)/N1(2) ELSE ART=0
5440 IF C1(2)<>0 THEN ACRT=ST9(2)/C1(2) ELSE ACRT=0
5450 PRINT CHR$(27);CHR$(69)
5460 PRINT #2,USING "###";SN;ZZ;NC(SN);KN;3;N1(2);C1(2);
5470 PRINT #2,USING "####.##";ART;ACRT
5480 REM IF CRI$="YES" THEN GOTO 4832
5490 PRINT CHR$(27);CHR$(89);CHR$(40);CHR$(32);"    "
5500 PRINT "TASK","# RESP","% CORRECT","CORRECT R.T."
5510 PRINT "====","======","=========","============"
5520 IF C1(2)<>0 THEN C1(2)=(C1(2)/N1(2))*100
5530 PRINT "DELAYED R.T.",N1(2),C1(2),ACRT
5540 POKE 8220,0: POKE 8219,0
5550 W1=PEEK(8220)
5560 IF W1<15 THEN GOTO 5550
5570 PRINT CHR$(27);CHR$(69);
5580 RETURN
5590 FIRST$="Y": S2=4: T4=0
5600 POKE 8220,0: POKE 8219,0
5610 IF T1$<>"M" AND T2$<>"M" THEN GOTO 5630
5620 GOSUB 2660: MFIRST$="N"
5630 IF T1$<>"C" AND T2$<>"C" THEN GOTO 5650
5640 GOSUB 3610: CFIRST$="N"
5650 IF T1$<>"V" AND T2$<>"V" THEN GOTO 5670
5660 GOSUB 4790: VFIRST$="N"
5670 DEF USR0=VARPTR(U0%(0)): K%=USR0(0)
5680 S1$=CHR$(K%)
5690 LOW=PEEK(8219): HIGH=PEEK(8220)
5700 T8=LOW/500 + HIGH/2
5710 IF T8>120 THEN GOTO 5860
5720 IF (T1$="M" OR T2$="M") AND (S1$="J" OR S1$="K") THEN II=0∂
        ELSE IF (T1$="C" OR T2$="C") AND (S1$="D" OR S1$="F") THEN II=1∂
         ELSE IF (T1$="V" OR T2$="V") AND (S1$="Q" OR S1$="W" OR S1$="O" OR S1$="P")
       THEN II=2∂
          ELSE GOTO 5670
5730 T0=T7(II)
5740 IF FIRST$="Y" THEN GOTO 5760
```

```
5750 IF S2<>II THEN T7(II)=T4
5760 T9=T8-T7(II)
5770 T0=T8-T0
5780 FIRST$="N"
5790 IF T9>=0 THEN GOTO 5830
5800 IF HIGH <> T5(II) THEN GOTO 5920
5810 T7(II)=T7(II)-.5: T9=T8-T7(II)
5820 T0=T0+.5
5830 IF S1$="J" OR S1$="K" THEN GOSUB 2660 @
        ELSE IF S1$="D" OR S1$="F" THEN GOSUB 3610 ELSE GOSUB 4790
5840 IF TUP$="Y" THEN GOTO 5860
5850 GOTO 5670
5860 PRINT CHR$(27);CHR$(69);
5870 FOR KJ=1 TO 50: NEXT KJ
5880 PRINT CHR$(27);CHR$(89);CHR$(40);CHR$(32);" "
5890 REM IF CRI$="YES THEN GOTO 5070
5900 PRINT "TASK","# RESP","% CORRECT","CORRECT R.T."
5910 PRINT "----","------","---------","------------"
5920 IF T1$<> "M" AND T2$<>"M" THEN GOTO 6050
5930 IF N1(0)<>0 THEN ART=ST9(0)/N1(0) ELSE ART=0
5940 IF C1(0)<>0 THEN ACRT=ST9(0)/C1(0) ELSE ACRT=0
5950 FOR I=1 TO 2
5960 IF C2(I,1)<>0 THEN C3(I,1)=N3(I,1)/C2(I,1) ELSE C3(I,1)=0
5970 IF N2(I,1)<>0 THEN N3(I,1)=N3(I,1)/N2(I,1) ELSE N3(I,1)=0
5980 NEXT I
5990 PRINT #2,USING "###";SN;ZZ;NC(SN);KN;1;N1(0);C1(0);
6000 PRINT #2,USING "####.##";ART;ACRT;N2(1,1);C2(1,1);N3(1,1);C3(1,1)
     ;N2(2,1);C2(2,1);N3(2,1);C3(2,1)
6010 IF N1(0)<>0 THEN C1(0)=C1(0)/N1(0)
6020 C1(0)=C1(0)*100
6030 REM IF CRI$="YES" THEN GOTO 5110
6040 PRINT "MATH";N1(0);C1(0);ACRT
6050 IF T1$<>"C" AND T2$<>"C" THEN GOTO 6170
6060 FOR I=1 TO 2
6070 IF C2(I,2)<>0 THEN C3(I,2)=N3(I,2)/C2(I,2) ELSE C3(I,2)=0
6080 IF N2(I,2)<>0 THEN N3(I,2)=N3(I,2)/N2(I,2) ELSE N3(I,2)=0
6090 NEXT I
6100 IF N1(1)<>0 THEN ART=ST9(1)/N1(1) ELSE ART=0
6110 IF C1(1)<>0 THEN ACRT=ST9(1)/C1(1) ELSE ACRT=0
6120 PRINT #2,USING "###";SN;ZZ;NC(SN);KN;2;N1(1);C1(1);
6130 PRINT #2,USING "####.##";ART;ACRT;N2(1,2);C2(1,2);N3(1,2);C3(1,2)
     ;N2(2,2);C2(2,2);N3(2,2);C3(2,2)
6140 IF N1(1)<>0 THEN C1(1)=C1(1)/N1(1)
6150 C1(1)=C1(1)*100
6160 PRINT "COTRAN";N1(1);C1(1);ACRT
6170 IF T1$<>"V" AND T2$<>"V" THEN GOTO 6250
6180 IF N1(2)<>0 THEN ART=ST9(2)/N1(2) ELSE ART=0
6190 IF C1(2)<>0 THEN ACRT=ST9(2)/C1(2) ELSE ACRT=0
6200 PRINT #2,USING "###";SN;ZZ;NC(SN);KN;3;N1(2);C1(2);
6210 PRINT #2,USING "####.##";ART;ACRT
6220 IF N1(2)<>0 THEN C1(2)=C1(2)/N1(2)
6230 C1(2)=C1(2)*100
6240 PRINT "DELAYED R.T.",N1(2),C1(2),ACRT
6250 POKE 8220,0: POKE 8219,0
6260 WL=PEEK(8220)
6270 IF WL<10 THEN GOTO 6260
6280 PRINT CHR$(27);CHR$(69);
6290 RETURN
```

APPENDIX B

INSTRUCTIONS FOR SUBJECTS

TASK INSTRUCTIONS

Mental arithmetic task.

In this task you will be presented with three 2-digit numbers and a numerical answer, for example

67 ! 44 ? 72 = 39

The task consists of (1) summing the first two numbers and subtracting the third number; (2) comparing your answer to the one displayed; and (3) responding whether the displayed answer is correct or incorrect. In the example above, 66 + 44 - 72 does equal 39, which is the answer displayed, so you would respond that the answer is "correct."

On the keyboard below the display will be located two sets of keys marked "C" and "I", which stand for correct and incorrect, respectively. For this task, use the keys on the right side of the keyboard to register your response. If the answer displayed is correct, press the key labelled "C", while if the answer is incorrect, press the key labelled "I". For the example above the answer is correct and therefore you would press the key on the right side of the keyboard labelled "C".

For the problem 67 ! 44 ? 72 = 40, your correct response would be to press the right key labelled "I" since the displayed answer is not correct. Approximately one-half of the displayed answers will be incorrect.

After you have pressed one of the two keys you will receive immediate feedback or information about your response. If your response is correct (that is, if you pressed "C" when the displayed answer was in fact correct or "I" when it was not correct) you will see a "*" appear directly to the right of the problem. If your response was incorrect, a "*" will not appear. Directly after, a new problem will be presented on the screen.

At the end of each 2-minute trial, your performance will be summarized and displayed on the screen, like this

TASK	# RESP	% CORRECT	CORRECT R.T.
MATH	54	95.3	3.5885

The MATH on the the left identifies this as the mental arithmentic task. the # RESP indicates how many problems were answered during the trial and the % CORRECT refers to the correct response time, that is, the average response interval between correct answers.

While you are performing the mental arithmetic task, try to answer the problems as quickly as possible while maintaining about a 95% level of accuracy. During the practice session, try to reduce the CORRECT R.T. on each trial, as compared to the previous trial.

If you have any questions, please ask the experimenter.

TASK INSTRUCTIONS

Code transformation (COTRAN) task.

In this task you will be presented with a line of type which has three 3-letter sequences, for example,

ABC BCA = CAB

Your task will be to (1) decide whether the third letter sequence (CAB) is correct or incorrect, given the changes from the first to the second sequences of letters, and (2) respond whether the third sequence is correct or not by pressing a key.

Look at the example above. In the first place of sequence 1, there is an "A"; in the first place in sequence 2 there is a "B". Thus, from sequence 1 to sequence 2, the "A" changes or is transformed to a "B". In order to be correct, the third sequence must also show the same changes from sequence 2 as sequence 2 does from sequence 1. In the example, the "A" in sequence 2 is in column 3 and in column 3 of sequence 3 there is a "B". Thus the same change or transformation occurs.

Now look at the letters is the second columns of the first two sequences. The letters are "B" (sequence 1) and "C" (in sequence 2). Looking now from sequence 2 to 3, the correct sequence would be to find the "B" in sequence 2 in the same column as the "C" in column 3. Looking at the second letters in those sequences, you will find this to be true.

Finally, carry out the same procedure with the third letter. From sequence 1 to 2, the "C" changes to "A", and from sequence 2 to 3, the "C" also changes to "A". Thus the third sequence is correct. Any other order of the three letters would be incorrect, as you can easily verify by changing the order in sequence 3.

Now take the problem XJL JLX = XLJ. The "X" in sequence 1 changes to a "J" in sequence 2; the "X" in sequence 2 also changes to a "J" in sequence 3. However, the "J" in column 2 of sequence 1 changes to a "L" in column 2 of sequence 2, but the "J" in sequence 2 (column 1) changes to an "X" in sequence 3. Thus the problem is incorrect. the correct sequence is LXJ.

You should make your responses in the same way as the mental arithmetic task. On the left side of the keyboard under the COTRAN task are two buttons, labelled respectively "C" and "I". If the third sequence of letters in the COTRAN task (that is, the answer) is correct, press the key labelled "C", while if the sequence is wrong, press the key labelled "I". In the first example, the correct response would have been to press the "C"; in the second example, the correct response would be to press the "I". Approximately one-half of the problems presented will be incorrect.

After you have pressed one of the two keys, you will receive feedback about your response. If you responded correctly, a "*" will be presented to the immediate right of the problem. If your response was incorrect no "*" will appear. Directly after, a new problem will be presented.

At the end of each 2 minure trial your performance will be summarized and displayed on the screen as follows:

TASK	# RESP	% CORRECT	CORRECT R.T.
COTRAN	56	93	3.67

The "COTRAN" identifies the task. "# RESP" refers to the total number of problems attempted during the trial and the "% CORRECT" is the percentage of correct responses out of the total. The "CORRECT R.T." refers to the correct response time, that is, the average response interval between correct answers.

While you are performing the COTRAN task, try to answer the problems as quickly as possible while maintaining about a 95% level of accuracy. During the practice session try to reduce the CORRECT R.T. on each trial as compared with the previous trial.

If you have any questions, please ask the experimenter.

TASK INSTRUCTIONS

Delayed reaction time task.

In this task, target signals (either a $ or &) will be presented one at a time on either the extreme right or the extreme left sides of the display (see figure).

Your task will be to remember the currently displayed symbol and location, while responding to the previous symbol/ location. In this task, you should respond by pressing the key labelled with the previous symbol under the appropriate location. After each response, the current signal will disappear and a new one will be presented.

At the beginning of the trial, one of the four signal/ locations will be presented, for instance, a $ on the left side. For this first signal, press the righthand key marked "$", which is just a signal to the computer that you have seen the first signal. When you press this key, the $ on the left will be erased and a new signal will appear, for instance, a & on the right. When you see the second signal, press the key which corresponds to the first signal--a $ on the left in this case. When you see the third signal, press the key which corresponds to the second signal (the & on the right), and so on, until the end of the trial. After each response a new symbol/location will be presented regardless of whether your response was correct or not.

Try to preform this task as quickly as possible while maintaining a level of 95% accuracy.

If you have any questions regarding this task, please ask the experimenter.

PRACTICE SESSION

During this part of the experiment you will be provided with practice on the mental arithmetic and code transformation tasks. Each of the tasks will be presented to you for 12 trials. Each trial will last for 2 minutes and after each trial you will be shown a summary of your performance for the task. After each four trials you will be given a one minute rest.

For each problem, respond as quickly as possible while maintaining a high level of accuracy. That is, on successive trials, try to obtain a smaller correct response time (Correct R.T.) than on the preceding trial while maintaining 95% accuracy.

Learning each of the tasks is equally important, so please do not favor one task over another because you think it is more (or less) interesting, or difficult, or for any other reason. At first you will probably have to "work out" the answers to the problems, but after some practice you may have learned the correct answers to some or all of the problems.

REMEMBER: Try to learn to perform both tasks as well as you can in this practice session.

PRACTICE INSTRUCTIONS

During this phase of the experiment you will be provided with practice on the mental arithmetic and code transformation tasks. The two tasks will be presented to you at the same time for 24 trials. Each trial will last for 2 minutes and after each trial you will be shown a summary of your performance for each task. After each four trials you will be given a one minute rest.

For each problem, respond as quickly as possible while maintaining a high level of accuracy. Learn to coordinate your performance between the tasks so that you maintain the highest level that you are able on both tasks. On successive trials, try to obtain a smaller correct response time (Correct R.T.) than on the preceding trial while maintaining 95% accuracy.

Learning each of the tasks is equally important, so please do not favor one task over another because you think it is more (or less) interesting, or difficult, or for any other reason. At first you will probably have to "work out" the answers to the problems, but after some practice you may have learned the correct answers to some or all of the problems.
REMEMBER: Try to learn to perform the tasks together as well as you can in this practice session.

APPENDIX C

TESTS OF HOMOGENEITY OF VARIANCE

Table A-1

Summary of Tests of Homogeneity of Variance for the Measures in the Math Immediate Transfer Session

	Measure			
Distribution	RT	% Errors	CRI	log CRI
Single Old	1.356	0.978	1.407	1.692
Single New	1.960	1.954	1.619	0.704
Dual Old	0.407	1.461	1.358	0.809
Dual New	0.397	1.146	7.710*	2.342
Triple Old	0.144	0.740	2.942*	0.735
Triple New	0.762	2.396	4.109*	1.958

Note. Degrees of Freedom = 3,49

* $p < .05$

Table A-2

Summary of Tests of Homogeneity of Variance for the Measures in the Trigram Immediate Transfer Session

	Measure			
Distribution	RT	% Errors	CRI	log CRI
Single Old	1.454	1.174	0.953	1.110
Single New	1.790	0.157	1.746	1.796
Dual Old	0.707	12.630*	1.835	0.427
Dual New	0.569	3.861*	2.074	1.032
Triple Old	1.088	7.301*	1.904	0.769
Triple New	1.561	2.527	0.260	0.588

Note. Degrees of Freedom = 3,70

* $p < .05$

Table A-3

Summary of Tests of Homogeneity of Variance for the Measures in the Math Retention Transfer Session

	Measure			
Distribution	RT	% Errors	CRI	log CRI
Single Old	0.349	2.234*	1.091	0.730
Single New	0.525	1.008	1.781*	1.068
Dual Old	0.718	1.266	2.072*	1.101
Dual New	0.997	0.492	1.062	0.771
Triple Old	1.516	0.850	4.116*	1.465
Triple New	1.066	1.702*	1.299	0.589

Note. Degrees of Freedom = 15,63

* $p < .05$

Table A-4

Summary of Tests of Homogeneity of Variance for the Measures in the Trigram Retention Transfer Session

	Measure			
Distribution	RT	% Errors	CRI	log CRI
Single Old	2.107	0.906	2.763*	1.883*
Single New	1.637	0.859	2.027*	1.716*
Dual Old	1.578	1.835*	2.583*	1.870*
Dual New	1.908*	3.046*	4.593*	2.080*
Triple Old	1.110	1.410	1.085	0.710
Triple New	1.010	2.065	1.559	0.731

Note. Degrees of Freedom = 15,63

* $p < .05$

AUTOBIOGRAPHICAL STATEMENT

Peter S. Winne was born May 13, 1947 in Philadelphia, Pa. He received his BA in English from the University of Virginia in 1969 and his MS from Old Dominion University in 1978. He has published three articles in collaboration with colleagues: Effects of whole body vibration in combined axes and with noise on subjective evaluation of ride quality (_American Industrial Hygiene Association Journal_, 1977); The range and consistency of individual differences in continuous work (_Human Factors_, 1980); and A longitudinal examination of rater and ratee effects in performance ratings (_Personnel Psychology_, 1983).

During his tenure at Old Dominion University, he has received numerous appointments as teaching assistant, research assistant, research associate, and part-time instructor. He is a member of Phi Kappa Phi and Sigma Xi honorary societies, as well as the American Psychological Association, Southern Society for Philosophy and Psychology, Human Factors Society and Tidewater Human Factors Society.